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TITLE OF THE INVENTION (500 characters max)

Advanced Short-Range Cellular Booster

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- ☐ Application Date Sheet. See 37 CFR 1.76
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METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

- ☑ Applicant claims small entity status. See 37 CFR 1.27.
- ☑ A check or money order is enclosed to cover the filing fees.
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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Advanced Short-Range Cellular Booster

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1/5/2004

1. INTRODUCTION

The existing cellular networks, such as GSM and IS95, are intended to provide a contagious and continuous coverage, so as to support the high terminal mobility expected from such systems. However, despite careful network design, indoor (in-building) coverage, or the coverage of places with high shadowing attenuation (e.g. tunnels) of such networks is often "patchy", with "coverage Holes" at best, and no coverage at worst. The reason for the impaired indoor coverage is that the cellular base stations are usually placed outside buildings, higher than the average building heights, to provide large area coverage. Although the signal may be adequate at "street-level", it is severely attenuated by the building material, reducing the signal power in-building, resulting in the poor converges. This loss of signal power (attenuation) depends on the building material and can be tens of dBs for each wall penetration. This problem is exacerbated in the 3rd generation systems such as GSM-EDGE, WCDMA and cdma2000, as these new systems have the capability of high data transmission, which results in lower information bit energy (E_b), and much reduced link budget and cell foot-print. Currently, the common solutions for providing indoor coverage are:

I) More outdoor base stations in the same geographical area, supporting smaller cell sizes.
II) Microcells.
III) Picocells (in-building cells).
IV) Conventional repeaters.

Clearly all the above solutions (except the repeater solution) are very expensive and require extensive investment in the cellular network infrastructure and are much more complex in planning and operation. There are other solutions such as repeaters that can be used to boost the signal in a given geographical area.

The repeater solution, although cheaper than a base station, has several drawbacks. These outdoor repeaters are still too expensive for a private user, and require careful planning. Most require large directional antennas, or additional backhaul frequencies to reduce antenna gain requirements, which result in lower spectral efficiency and is capacity limited. As repeaters tend to transmit the maximum allowed transmit power, they often cause increased interference in the network, and as such are not a preferred solution for the network operators. The indoor repeaters are still cheaper than the outdoor version, but require installation, high directional antennas on the roof, and ensured antenna isolation, which requires skilled installation and operation. Therefore, it is still too complicated for

an unskilled user and not sufficiently cheap to be used for providing very localized coverage area.

The invention discussed here provides better, and localized indoor coverage without causing excess interference in the network, or requiring costly equipment or network planning. The invention increases the overall network capacity, reducing the mobile and BTS transmit power, increasing the battery life and reducing the "harmful" radiation to the user.

2. INVENTION

The description of the invention is based on a GSM (Global System for Communications) network, which is a TDMA-FDD based system operating at various spectrum bands, depending on the country and the region's regulations. However, the invention, with minor modifications, is equally applicable to any other cellular system, including (but not limited to) IS95, cdma2000 and WCDMA, and with more modifications is applicable to to wireless LAN systems such as 802.11a, b, and g. Where the system differences require additional or modified features, it is stated in the relevant part. Although the description is given for cellular systems, with minor modifications, the invention can equally be applied to other systems such as GPS or any other system that requires signal-boosting capability. The operating frequency can be at any desired part of communications spectrum used for mobile communications (e.g. PCS 1900, or DCS1800 or GSM900 or UMTS 2000, ISM or UNII band). It is also understood that the description here is only intended as an example, and as such the utilization of the booster is not only limited to the in-building coverage and can be used in other places such as trains, planes, cars, tunnels, etc. Also, the example may not include all the required design details; it is written such that it is obvious to a person skilled in the art so that the system can be constructed with the following description. All the units and sub-units discussed and explained hereafter have to meet the regulations of the respective licensed and unlicensed band of operation. Therefore, for all the different example implementations of the invention provided hereafter, the maximum transmit power, spectral mask, out of band radiation and many other regulatory requirements for transmitters, receivers, repeaters and boosters, that are known to person of sufficient skill, have to be met for both, the considered licensed and the unlicensed band of operations. Finally, it is also understood that the description here is only intended as an example, and as such does not represent the full scope of the invention.

2.1 Analogue Implementation Example

Figure 100 shows a cellular network with two base stations (BTS1 (101) & BTS2 (102)). It is understood that a typical network supports more than two base stations. The invention is applicable to any size network, regardless of the supported number of base stations. BTS1 101 is connected to Base Station Controller BSC1 107. BTS2 102 is connected to Base Station Controller BSC2 108. BTS2 102 can also be connected to Base Station Controller BSC1 107, instead of BSC2 108, without any impact on the invention.

BSC1 107 is connected to Mobile Switching Center MSC 109. BSC2 108 is connected to MSC 109, or instead may be connected to another MSC in the network, which is not shown here, without any impact on the invention. MSC 109 is connected to PSTN 110. BTS1 101 has an associated coverage area 103. BTS2 102 has an associated coverage area 104. These coverage areas may or may not overlap. However, usually the network is planned such that there is considerable overlap, to facilitate handoffs. The mobile terminal 105 is inside building 106, in the coverage area 103 communicating with BTS1 101, using a traffic channel transmitted at around frequency $f1$ in the forward-link and its associated reverse-link frequency, $f1'$. This traffic channel can be one of the available time slots on the BCCH carrier, or may be on a TCH carrier, where frequency hopping may be used to reduce interference. Mobile terminal 105 may or may not be in coverage area 104, but it is understood that the mobile unit 105 is well within the coverage area 103 and that the average signal power from BTS1 101 is much stronger than the average signal power from BTS2 102, within the building 106, and the locality of mobile unit 105. The r.m.s. forward-link signal level $\hat{S}_1$, outside the building 106 is higher than the r.m.s. signal level $\hat{S}_2$, inside the building, by the wall penetration loss α. The loss α may be such that $\hat{S}_2$ is not at sufficiently high level for the mobile unit 105 to maintain reliable communication with BTS1 101, or BTS2 102, or both BTS1 101 and BTS2 102. Further, the signal level $\hat{S}_2$ may be such that mobile unit 105 may have difficulty to setup and maintain a communication link with BTS1 101 or BTS2 102, or both BTS1 101 and BTS2 102, or the communication link does not have the required performance and reliability, in all or some of the in-building areas. The coverage problem inside the building 106 may be solved by more transmit power from BTS1 101 in the down-link to combat the signal loss, by the wall penetration loss, α. The r.m.s. reverse-link signal level $\hat{S}`_1$, inside the building 106 is higher than the r.m.s. signal level $\hat{S}`_2$, outside the building, by the wall penetration loss $\alpha`$. The loss $\alpha`$ may be such that $\hat{S}`_2$ is not at sufficiently high level for the mobile unit 105 to maintain reliable communication with BTS1 101, or BTS2 102, or both BTS1 101 and BTS2 102. Further, the signal level $\hat{S}`_2$ may be such that mobile unit 105 may have difficulty to setup and maintain a communication link with BTS1 101 or BTS2 102, or both BTS1 101 and BTS2 102, or the communication link does not have the required performance and reliability, in all or some of the in-building areas. The coverage problem inside the building 106 may be solved by more transmit power from mobile unit 105 in the up-link to combat the signal loss, by the wall penetration loss, $\alpha`$. Usually the forward and reverse link frequency pairs are sufficiently close, such that $\alpha$ level is substantially similar to $\alpha`$ level.

Figure 200 depicts the forward-link part 230 of the novel device. The novel device 230 in its simplest form would provide better indoor coverage, by boosting the signal level in building in the forward-link of the cellular network. BTS1 213 has a BCCH radio channel (beacon channel) transmitted substantially close to $f1$. BTS1 213 is in communications with the mobile unit 214 at a frequency substantially close to $f1$ (the BCCH carrier frequency) or another carrier frequency, $f2$, that may or may not be frequency hopping. There may or may not be other frequencies that are transmitted by BTS1 213, or other base stations in the same area, which are not shown in the figure 200.

The device has two separate units, the "Forward-link Network unit" 201, which is placed where good signal coverage exists, indoor or outdoors, and the "Forward-link User unit" 202, which is placed where good signal coverage does not exist, indoor or outdoors. The Forward-link Network unit 201 is connected to an antenna 203, tuned to operate at the cellular network operating frequency band. The Forward-link Network unit 201 is also connected to an antenna 204 tuned to operate at suitable Unlicensed National Information Infrastructure (known as U-NII) bands, where the system is designed to operate at U-NII spectrum bands. Subject to the relevant regulations, the system can also be designed to operate at Unlicensed Personal Communications Services (U-PCS) band or at Industrial, Scientific and Medical (ISM) band of frequencies. The choice of the unlicensed frequency depends on the design of the equipment and the system specification. For the purposes of this invention description, the frequencies defined in the portion of the radio spectrum known as U-NII bands are considered in the system design. Some design modifications are required, for ISM band operation. The modifications are related to the minimum spreading factor of 10 required for the ISM band operation, and the maximum allowed transmit power. If the system is designed to operate in ISM band, the signal requires further spread spectrum modulation/demodulation and other modifications to meet the Required FCC 47 CFR Part-15, subpart E requirements.

The frequency bands defined for U-NII operations are as follows:

1) 5.15-5.25 GHz @ Max Transmit power of 2.5 mW/MHz
2) 5.25-5.35 GHz @ Max Transmit power of 12.5mW/MHz
3) 5.725-5.825 GHz @ Max Transmit power of 50 mW/MHz

Any unlicensed operation in U-NII band is allowed, as long as the signal transmissions meet FCC 47 CFR Part-15. So the operation of the booster described here has to meet all the requirements of the FCC 47 CFR Part-15 (subpart E for U-NII frequencies), which are assumed to be known to person with sufficient skills in the art. The most important of these regulations are the transmit power and undesirable emission limits and the antenna gain limits, which all have to be met for an acceptable device.

The "Forward-link User unit" 202 is connected to an antenna 205 tuned to operate in the same frequency band as antenna 204, which is U-NII band in this example. The Forward-link User unit 202 is also connected to an antenna 206 tuned to operate at the required cellular network operating band.

Antenna 203 is connected to a (Low Noise Amplifier) LNA unit 207, which is further connected to a bandpass filter 232. LNA unit 207 is preferably a high performance amplifier, with a typical gain of 15dB and a noise figure of 1.5dB with sufficient bandwidth to cover the required portion of the spectrum. The bandpass filter 232 can be designed to pass all or a desired part of the interested cellular spectrum, or can be a bank of overlapping bandpass filters, covering the full spectrum of the interested cellular system, with a RF switch, such that the desired band and bandwidth can be selected manually or automatically. The bandpass filter 232 is connected to frequency converter 208. The frequency converter 208 is capable of converting the cellular network operating

spectrum band to a desirable part of the U-NII spectrum, and includes all the necessary components, such as mixers and filters, for correct operation. The frequency converter 208 is connected to the Forward-link Network unit transmitter 209. The transmitter unit 209 is designed to operate in U-NII band and conforms to the FCC 47 CFR Part-15, subpart E regulations, and can be as simple as a single amplifier operating at the desirable U-NII operation band, or more complex transmitter with amplifiers and filters, or even a WLAN transmitter such as 802.11a. The transmitter unit 209 is connected to antenna 204.

Antenna 205 is connected to the Forward-link User unit receiver 210, which is designed to receive the signal transmitted by unit 201. The receiver 210 which is connected to frequency converter 211, can be as simple as a single LNA operating at desirable U-NII band of device operation, or it can be better designed with additional functionalities such as AGC, several cascaded amplification stages and variable channel select filters, or even a WLAN receiver such as 802.11a (where the transmitter part of 802.11a is used in the Network unit 209). If AGC is used in receiver 210 and the unit is design for CDMA cellular networks, care has to be taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. Frequency converter unit 211, which is connected to receiver unit 210 and variable gain amplifier unit 212, converts the input signals, from U-NII band, to the cellular network operating frequencies, and includes all the necessary components, such as mixers and filters, for correct operation. The frequency converter unit 211 performs the opposite conversion operation of the frequency converter unit 208, and includes all the necessary components, such as mixers and filters, for correct operation. The frequency converter 211 is connected to the Variable Gain (VG) amplifier 212, operating at the cellular network operating frequency band. The variable gain amplifier 212 is connected to antenna 206. Antenna 206 will be transmitting signals with substantially similar frequencies to the frequencies transmitted by base station 213, and has to meet the required cellular system specifications.

The signal radiated by antenna 206, which is an amplified repeated version of the *original* incident signal received by antenna unit 203, will experience some loss in the power level, before returning and *re-entering* the antenna 203 again. The said *re-entered* signal into antenna 203 is termed "Down-link Returned-Signal" hereafter. The ratio of the r.m.s. signal value of the Down-link Returned-Signal to the r.m.s. value of the *original* incident signal at the output of the antenna 203 terminator, with all the system and propagation path delays between the antenna units 206 and 203 removed, is the Down-link Returned-Signal path loss, and is termed here as the "Down-link System Path Loss" and referred to as PL_{dl}.

Further, the "Down-link System Link Gain", which is here referred to as G_{dl}, is defined as "the ratio of the r.m.s. signal value at the input to the antenna 206 terminator, to the r.m.s. signal value, at the antenna 203 terminator, where the Down-link System Path Loss, PL_{dl}, as defined above, is infinite (i.e. no EM coupling path between antenna 206 and antenna 203), and all the system and propagation path delays (from antenna 203, through the system to antenna 206) are removed".

The variable gain amplifier unit 212 gain is set such that Down-link System Link Gain, G_{dl}, is less than the Down-link System Path Loss, PL_{dl}, by the amount of "Down-link Gain Margin", dg_{dl}, so as to avoid a "positive feed-back" loop in the system, i.e.

$$G_{dl} = PL_{dl} - dg_{dl} \text{ (dB)}$$

Note that all values of PL_{dl}, G_{dl}, and dg_{dl} are all in dB. The value of dg_{dl} ranges from 0 to PL_{dl}, and can be assumed to be 15 dB for the purposes of the description here. However, it is possible to select better values for dg_{dl}, where the system performance is optimized further.

Figure 300 depicts the reverse-link part 330 of the novel device. The reverse-link part of the novel device 330 in its simplest form would provide better indoor coverage, by boosting the signal level in building in the reverse-link of the cellular network, to such level that is needed for acceptable link performance. BTS1 302 has a BCCH radio channel (beacon channel) transmitted substantially close to ***f1***, and a frequency pair, ***f'1*** on the reverse-link. BTS1 302 is in communications with the mobile unit 324 at a frequency substantially close to ***f'1*** (the BCCH carrier frequency) or another carrier frequency, ***f'2***, that may or may not be frequency hopping. There may or may not be other frequencies that are transmitted by BTS1 302, or other base stations in the same area, which are not shown in the figure 300.

The device has two separate units, the "Reverse-link Network unit" 326, which is placed where good signal coverage exists, indoor or outdoors, and the "Reverse-link User unit" 328, which is placed where good signal coverage does not exist, indoor or outdoors. The Reverse-link Network unit 326 is connected to an antenna 304, tuned to operate at the cellular network operating frequency band. The Reverse-link Network unit 326 is also connected to an antenna 312 tuned to operate at suitable Unlicensed National Information Infrastructure (U-NII) bands, where the system is designed to operate at U-NII bands. Subject to the relevant regulations, the system can also be designed to operate at Unlicensed Personal Communications Services (U-PCS) band or at Industrial, Scientific and Medical (ISM) band of frequencies. The choice of the unlicensed frequency depends on the design of the equipment and the system specification. For the purposes of this invention description, the frequencies defined in the portion of the radio spectrum known as U-NII bands are considered in the system design. Some design modifications are required for ISM band operation. The modifications are related to the minimum spreading factor of 10 required for the ISM band operation, and the maximum allowed transmit power. If the system is designed to operate in ISM band, the signal requires further spread spectrum modulation/demodulation and other modifications to meet the FCC 47 CFR Part-15, subpart E requirements.

The frequency bands defined for U-NII operations are as follows:

1) 5.15-5.25 GHz @ Max Transmit power of 2.5 mW/MHz

2) 5.25-5.35 GHz @ Max Transmit power of 12.5mW/MHz
3) 5.725-5.825 GHz @ Max Transmit power of 50 mW/MHz

Any unlicensed operation in U-NII bands is allowed, as long as the signal transmissions meet with FCC 47 CFR Part-15. So the operation of the booster described here has to meet all the requirements of the FCC 47 CFR Part-15 (subpart E for U-NII frequencies), which is assumed to be known to person with sufficient skills in the art. The most important of these regulations are the transmit power and undesirable emission limits and the antenna gain limits, which all have to be met for an acceptable device.

The "Reverse-link User Unit" 328 is connected to an antenna 314 tuned to operate in the same frequency band as antenna 312, which is U-NII band in this example. The Reverse-link User unit 328 is also connected to an antenna 322 tuned to operate at cellular network operating band.

Antenna 322 is connected to a LNA unit 320, which is further connected to a bandpass filter 321. LNA unit 320 is preferably a high performance amplifier, with a typical gain of 15dB and a noise figure of 1.5dB with sufficient bandwidth to cover the required portion of the spectrum. The bandpass filter 321 can be designed to pass all or a desired part of the required cellular spectrum, or can be a bank of overlapping bandpass filters, covering the full spectrum of the interested cellular system, with a RF switch, such that the desired band and bandwidth can be selected manually or automatically. The bandpass filter 321 is connected to frequency converter 318. The frequency converter 318 is capable of converting the cellular network operating spectrum band to a desirable part of the U-NII spectrum, and includes all the necessary components, such as mixers and filters, for correct operation. The frequency converter 318 is connected to the Reverse-link User unit transmitter 316. The transmitter unit 316 is designed to operate in U-NII band and conforms to the FCC 47 CFR Part-15, subpart E regulations, and can be as simple as a single amplifier operating at the desirable U-NII operation band, or a more complex transmitter with amplifiers and filters or even a WLAN transmitter such 802.11a. The transmitter unit 316 is connected to antenna 314. The desired portion of the U-NII band of operation for the reverse-link part of the booster is different to the desired portion of the U-NII band of operation for Forward-link part of the booster, and sufficiently apart, so that no substantial interference is experienced from the operation of one link, to the other.

Antenna 312 is connected to the Reverse-link Network unit receiver 310, which is designed to receive the signal transmitted by unit 328. The receiver 310 which is connected to frequency converter 308, can be as simple as a single LNA operating at desirable U-NII band of device operation frequency, or it can be better designed with additional functionalities such as AGC, several cascaded amplification stages and variable channel select filters or even a WLAN receiver such as 802.11a (where the transmitter part of 802.11a is used in the User unit 316). If AGC is used in receiver 310 and the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation

does not interfere with the closed-loop power control mechanism. Frequency converter unit 308, which is connected to receiver unit 310 and variable gain amplifier unit 306, converts the input signals, from U-NII band, to the cellular network operating frequencies, and includes all the necessary components, such as mixers and filters, for correct operation. The frequency converter unit 308 performs the opposite conversion operation of the frequency converter unit 318. The frequency converter 308 is connected to the variable gain amplifier 306, operating at the cellular network operating frequency band. The variable gain amplifier 306 is connected to antenna 304. Antenna 304 will be transmitting signals with substantially similar frequencies to the frequencies transmitted by mobile unit 324.

The signal radiated by antenna 304, which is an amplified repeated version of the *original* incident signal received by antenna unit 322, will experience some loss in the power level, before returning and *re-entering* the antenna 322 again. The said *re-entered* signal into antenna 322 is termed "Up-link Returned-Signal" hereafter. The ratio of the r.m.s. signal value of the Up-link Returned-Signal, to the r.m.s. value of the *original* incident signal, at the output of the antenna 322 terminator, with all the system and propagation path delays between the antenna units 304 and 322 removed, is the Up-link Returned-Signal path loss, and is termed here as the "Up-link System Path Loss" and referred to as PL_{ul}.

Further, the "Up-link System Link Gain" which here is referred to as G_{ul}, is defined as "the ratio of the r.m.s. signal value at the input to the antenna 304 terminator, to the r.m.s. signal value, at the antenna 322 terminator, where the Up-link System Path Loss, PL_{ul}, as defined above, is infinite (i.e. no EM coupling path between antenna 304 and antenna 322), and all the system and propagation path delays (from antenna 322, through the system to antenna 304) are removed".

The variable gain amplifier unit 306 gain is set such that Up-link System Link Gain, G_{ul}, is less than the Up-link System Path Loss, PL_{ul}, by the amount of "Up-link Gain Margin", dg_{ul}, so as to avoid a "positive feed-back" loop in the system, i.e.

$$G_{ul} = PL_{ul} - dg_{ul} \text{ (dB)}$$

Note that all values of PL_{ul}, G_{ul}, and dg_{ul} are in dB. The value of dg_{ul} ranges from 0 to PL_{ul}, and can be assumed to be 15 dB for the purposes of the description here. However, it is possible to select better values for dg_{ul}, where the system performance is optimized further.

Usually the forward and the reverse links frequency pairs are sufficiently close, such that G_{ul} level is substantially similar to G_{dl} level, and PL_{ul} level is substantially similar to PL_{dl} level and dg_{ul} level is substantially similar to dg_{dl} level.

It is also possible to transmit a unique booster unit identity code, and optionally the device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded

(protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the reverse-link Network unit 326. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the reverse-link Network unit 326. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station, requires base station receiver modifications, but does not affect the normal operation of the cellular link.

Figure 500 shows the Network unit 502, together with the User unit 504 in the same diagram. The Forward-link Network unit 514 (201 in figure 200) and the Reverse-link Network unit 516 (326 in figure 300) are now in one unit, referred to hereafter as the Network unit 502. The Forward-link User unit 518 (202 in figure 200) and the Reverse-link User unit 520 (328 in figure 300) are now in one User unit, referred to hereafter as the User unit 504. In figure 500, the transmit/receive antenna 203 in figure 200 and transmit/receive antenna 304 in figure 300 are replaced by a single antenna 506 and duplex filter 528. The duplex filter unit 528 is designed for optimum performance, and has to meet the required specification for cellular operation. Also, the transmit/receive antenna 204 in figure 200 and transmit/receive antenna 312 in figure 300 are replaced by a single antenna 508 and duplex filter 526. Further, the transmit/receive antenna 205 in figure 200 and transmit/receive antenna 314 in figure 300 are replaced by a single antenna 510 and duplex filter 524 in figure 500. Equally, the transmit/receive antenna 206 in figure 200 and transmit/receive antenna 322 in figure 300 are replaced by a single antenna 512 and duplex filter 522 in figure 500. The duplex filter unit 522 is designed for optimum performance, and has to meet the required specification for cellular operation. It is understood that GSM system is a FDD system, and as such reverse-link frequencies are different to that of the forward-link frequencies. In such system a duplex filter provides the required functionality. However, if the Network unit 502 and the User unit 504 are designed for a TDD system, the duplexers 528 and 522 can be replaced by hybrid combiners or "circulators". However, duplexers 526 and 524 are still required, as the forward-link and reverse-link frequencies in the U-NII band have to be kept separate (i.e. FDD). With minor modifications, it is possible that, instead of antennas 508 and 510, a coaxial cable (such as RG58 or IS inch heliax) is used to connect the Network unit 502 to the User unit 504. In such an arrangement, where coaxial cable is used for the link connection, although still possible, there is no need for up-conversion to U-NII bands, and the system can operate with the Forward and reverse-link signals kept at their original cellular frequencies.

Transmit power level for the Network Unit 502, in the cellular band, is in the range of –10dBm to 37dBm, with a down-link receiver sensitivity of about –110dBm to –120 dBm. Transmit power level for the User Unit 504, in the cellular band, is in the range of –20 dBm to 0dBm, with a up-link receiver sensitivity of about –110dBm to –120 dBm.

The booster system as described above will only work satisfactorily in limited scenarios, where the isolation between antennas 506 and 512 is more than the up-link and down-link System Link Gains. To ensure the correct operation of the booster system in all propagation and operating conditions, and without the need for the directional antennas, there are several important features that need to be included in the system design.

1- Since both the Network unit 502 and the User unit 504 are for most time stationary relative to each other, and possibly other network elements such as base stations, antenna (space) diversity has to be used for transmit and receive operations.

2- The signals transmitted by antenna 506, in the reverse-link, are substantially at the same operating frequency band as the reverse-link signals received by antenna unit 512. Equally, the signals transmitted by antenna 512, in the forward-link, are substantially at the same operating frequency band as the forward-link signals received by antenna unit 506. As the signals received by the Forward-link Network unit 514 are transmitted to Forward-link User unit 518, via antenna units 508 and 510, and further, as the signal received by the Forward-link User unit 518 is then amplified before the retransmission via antenna unit 512, a feed-back loop, through the antennas 512 and 506, between the two Forward-link Network unit 514 and Forward-link User unit 518 exists. Any gain in this loop will cause "positive feed-back", which results into unstable operation (as discussed previously). This is also true for the reverse-link operation of the Network unit 502 and the User unit 504. As discussed previously, in order to keep these two feed-back loops in a stable operating region, in the forward-link, the Down-link System Link Gain, G_{dl}, has to be less than the Down-link System Path Loss, PL_{dl}, by dg_{dl}, so as to avoid a "positive feed-back" loop in the system, i.e. $G_{dl} = PL_{dl} - dg_{dl}$ (dB). Equally, in the reverse-link, the Up-link System Link Gain, G_{ul}, has to be less than the Up-link System Path Loss, PL_{ul}, by dg_{ul}, so as to avoid a "positive feed-back" loop in the system, i.e. $G_{ul} = PL_{ul} - dg_{ul}$ (dB). The propagation losses, PL_{ul} and PL_{dl}, may be due to shadowing, distance and antenna radiation pattern and multipath propagation as well as wall penetration loss. The levels of these propagation losses, PL_{ul} and PL_{dl}, are not readily available and have to be measured.

3- The continuous and correct operation of the Network unit 502 and User unit 504 has to be monitored. Any operational problem at the Network unit 502 or the User unit 504 can result in unwanted transmissions in either forward or reverse (or both) links. Further, the system may rely on radio channels operating at unlicensed frequency bands, which are prone to interference from other unlicensed devices. Also, the operation of the Network unit 502 and the User unit 504 has to be coordinated. Therefore a control-signaling channel is required between the two Network 502 and the User 504 units.

4- The local oscillators of the network unit 502 and the User unit 504 have to be substantially similar in frequency, as any large frequency error between the Network 502 and the User 504 units will result in an unacceptable cellular link performance.

5- In conventional repeaters, the required isolation between the antennas 512 and 506 is normally provided by the use of directional antennas, which inherently have large apertures, leading to large size antennas. In order to provide maximum RF isolation between the antennas 512 and 506, advanced adaptive temporal and spatial signal processing techniques need to be used, so that antenna directivity requirements can be relaxed.

2.1.1 Advanced Features

The novel design solutions to the above five mentioned problems are discussed here.

Figure 600 shows the Network unit 602 (502 in figure 500) with the new design features included. Two antennas 610 and 608 are used for antenna diversity, instead of a single antenna 506 in figure 500. Also two antennas 636 and 638 are used for antenna diversity, instead of a single antenna 508 in figure 500. Although any diversity-combining scheme such as Maximal Ratio Combining, etc. can be used for the receiver chain, and transmit diversity schemes such as random phase change in one or both antennas for the transmitter chain, a simple scheme that is based on antenna switched diversity is suggested here for the receiver part. The switching can be continuous or based on received signal power level. Therefore, the RF switch 612 connected to duplexers 614 and 613 and the Forward-link Network unit 604 will provide switching operations for the cellular receive operation of the Network unit 602. Also, the RF switch 634 connected to antennas 636 and 638 and the duplex filter 632, will provide switching operations for the U-NII band transmit/receive operation of the Network unit 602. The duplex filters 614 and 613 are also connected to antennas 610 and 608 on one side, and the Complex-Weight unit 648 on the other side, as well as the RF switch unit 612. The complex-weight unit 648 is connected to power-splitter (hybrid combiner) 646 and the micro-controller 626. The power-splitter (hybrid combiner) 646 is connected to Reverse-link Network unit 606 via the directional coupler 618. All the directional couplers in this invention may be 17dB directional couplers. Also, the duplex filter 632 is connected to Forward-link Network unit 604 via the directional coupler 630, and Reverse-link Network unit 606 via the directional coupler 616. It is also possible to use hybrid combiners instead of the directional couplers 618, 630 and 616. It is also possible, and is more desirable, to place the Reverse-link Network unit 606 receiver unit 310 internal LNA, before the directional coupler 616 (or the hybrid combiner replacement) in diagram 600.

A calibration signal generator/transmitter unit 622 is coupled to the reverse-link transmitter path of the Network unit 602, via the directional coupler 618. The unit 622 will provide a channel-sounding signal, which is used to establish the complex channel characteristics which exist between the Network unit 602 antennas 608 and 610, and the input to the calibration signal receiver 620. The channel-sounding signal generated by unit 622 is transmitted via the complex-weight unit 648 and the diversity antennas 610 and 608 with a maximum transmit level, which is substantially below any expected signal level from cellular network (e.g. 20 dB below the minimum expected cellular signal level). The combined transmitted channel-sounding signal level, and the processing gain used in the calibration signal receiver unit 620 have to be equal to (or less than) the Up-link Gain Margin (dg_{ul}). The channel-sounding signal generated by unit 622 is a direct-sequence spread spectrum signal modulated by a known Pseudo Random (PN) code with a known code phase (referred to hereafter as "own code" phase) and with a chipping rate comparable to the forward and reverse links of the Network unit 602 and User unit 702 (in figure 700) operating bandwidths (e.g. 5Mchips/s for 5MHz bandwidth) and a

minimum code length to provide the required processing gain, which has also a code length (in time) longer than the maximum expected path delay (a code length of 1000 chips is adequate for most scenarios). The channel-sounding signal can be transmitted continuously or transmitted only when it is required. The code phases have to be selected such that the minimum code phase difference is larger than the maximum expected path delay (measured in multiple number of chips), and after that the code phases should be multiple integer of the minimum code phase. The calibration signal receiver unit 620 which is coupled to the reverse-link receive path of the Network unit 602, by directional coupler 616, using the known PN code and the transmit code phase is then capable of detecting and demodulating the channel-sounding signal transmitted by unit 622, which has entered the reverse-link path via the mentioned closed-loop mechanism that exists between the Network unit 602 and the User unit 702 in figure 700 (504 in figure 500). The calibration signal receiver unit 620 is capable of establishing the received signal strength and phase (complex channel impulse response that exists between the Network unit 602 combined outputs of antennas 608 and 610, and the input to the calibration signal receiver 620), either by correlation operation, similar to a RAKE receiver path searcher, or by matrix inversion operation on an appropriate block of sampled received signal, as discussed in the appendix A. The calibration signal receiver unit 620 includes many sub-units, including a frequency converter, to return the calibration signal to base-band frequencies and other units such as A/D converters and base-band processors to perform the necessary base-band algorithms, which are not shown in the diagram. The PN code phase can be assigned uniquely, or drawn according to a random algorithm, such that the probability of two units having the same code phase can be very low. Other code offset assignment strategies are also possible, such as dynamic assignment, where the code offset is selected, if no such offset was detected in that geographical area. This feature will enable the calibration signal receiver 620 to be able to scan and receive "other code" phases, and hence establishing if there is any other signal coupling to or from other units, that may be operating in the same geographical area. Further, more than one code phases can be used, to establish the mentioned complex channel impulse response, so that the probability of detection by other systems is increased. This PN code used for the channel-sounding signal can be modulated with information about the identity of the Network unit 602. The carrier frequency of the transmitted channel-sounding signal is preferred to be at the operating cellular frequency band. However, it is also possible to use carrier frequencies in other bands, such as ISM band at 2.4GHz, for the transmission of the channel-sounding signal. In this alternative scenario, the calibration signal generator and transmitter 622 carrier frequency is placed as near as possible to the operating frequency band. The chipping rate and the transmit power of the channel-sounding signal PN code has to be such that the channel-sounding signal complies with the FCC 47 CFR Part-15 rules. Although the mentioned ISM band is not the same as the cellular operating band, nevertheless, it is close enough to enable the system to converge the spatial algorithm weights, to establish the weights W_0 and W_1, used in the complex-weight unit 648. Any antenna and propagation differences in average signal power and antenna behavior, between the ISM and cellular operating bands, can be investigated in the design phase and taken into account in the final system design.

The Equipment ID and reference frequency unit 624 basically generates a BPSK signal, modulated by the equipment ID number and placed at a suitable part of U-NII band, and is coupled to the transmitter path of the forward-link of the Network unit 602 via the directional coupler 630. This unit is "frequency locked" to the local oscillator of the Network unit 602. The carrier frequency of this signal is selected such that it does not cause an unacceptable interference to the main cellular signal in the transmit path of the forward-link of the Network unit 602, but is close enough for an optimum transmission bandwidth. Where the Network unit 602 and the User unit 702 use the mains electricity supply for their operations, it is possible to use the 60Hz (or 50Hz) mains oscillations, to "lock" the local oscillators of these two units, to a common frequency source. In this case, the 60Hz (or 50Hz) mains oscillations have to be converted, by suitable circuitry, to the desired frequency, for the operation of the Network unit 602 and the User unit 702.

The Control Link unit 628 is a radio link between the two, Network unit 602 and the User unit 702 in figure 700. It may be a simple proprietary link that operates in one of the unlicensed band of frequencies, or may be an in-band control signaling, multiplex with the cellular signal path. It may also be a standard wireless link such as 802.11b, 802.11a or Bluetooth, designed to operate in unlicensed frequency band. The control link unit 628 is connected to micro-controller unit 626, and is able to communicate with this unit through an appropriate interface. The control link unit 628 is also connected to antennas 644 and 642 for transmission and reception of the control signals. If operating bandwidth and frequencies allow, with minor modifications to unit 602, antenna units 636 and 638 can also be used for the operation of control link unit 628. It has to be mentioned that it is also possible to keep the User unit 702 very simple, with all signal processing and control functionalities supported in the Network unit 602. In this case, there is either no need for control link unit 628, or a very simple control signaling such as in-band frequency tones, to set the required system bandwidth and gain in the User unit 702 is sufficient. Provided that the antenna bandwidth allows, with minor modifications to unit 602, antenna units 636 and 638 can also be used for control link unit 628 operations.

Micro-controller unit 626 is a simple micro-processor such as ARM7 or ARM9 with all the appropriate memory and interfaces. The micro-controller unit 626 is controlling the operation of the Network unit 602, and may perform some additional signal conditioning and processing such as signal level averaging and estimation and adaptive algorithms such as LMS and RLS where required. Some of the task of the micro-controller unit 626 is to set the operating bandwidth and set the weights W_0 and W_1, to communicate with and control the User unit 702 in figure 700, via the control link unit 628, to control and communicate with the calibration signal generator and transmitter 622 and calibration signal receiver 620, to operate the switching for the receiver antenna diversity and to monitor the correct operation of the Network unit 602 and User unit 702. Other tasks of the micro-controller 626 are discussed later by way of an example given in figures 800(a), 800(b), 800(c) and 820. Micro-controller unit 626 is connected to units 627, 628, 622, 606, 604, 620, 648 and 624, as well as the RF switches 634 and 612. The micro-controller 626, using the complex channel impulse response at the output of the calibration signal receiver unit 620, and using LMS (or RLS or QR-RLS or QR decomposition) computes the optimum values of the complex weights, W_0 and W_1, such

that the received complex channel impulse response at the output of the calibration signal receiver unit 620, is minimized in magnitude. With such transmit weights arrangement, the RF isolation (for up-link frequencies) between the Network unit 602 and the User unit 702 is adapted within the propagation channel, allowing the maximum possible overall ERP (Effective Radiated Power) from antennas 608 and 610, and hence the maximum coverage footprint.

Units 628, 622, 606, 604, 620, 624 are all connected to local oscillator unit 640, and derive their clock and reference frequencies from the local oscillator 640 signal. A simple user interface unit 627, which can be a keypad or simple dipswitch, is connected to micro-controller unit 626. The Network unit 602 has a unique "identity code", which can be set by the user interface unit 627, which is known to the micro-controller unit 626 and can be communicated to the User unit 702 micro-controller unit 728, or any other User units that may be within the operating range of Network unit 602.

Figure 700 shows the User unit 702 (504 in figure 500) with the new design features included. Two antennas 734 and 736 are used for antenna diversity, instead of a single antenna 512 in figure 500. Also two antennas 704 and 706 are used for antenna diversity, instead of a single antenna 510 in figure 500. Although any diversity-combining scheme such as Maximal Ratio Combining, etc. can be used for the receiver chain, and transmit diversity schemes such as random phase change in one or both antennas for the transmitter chain, a simple scheme that is based on antenna switched diversity is suggested here for the receiver part. The switching can be continuous or based on received signal power level. Therefore, the RF switch 732 connected to duplexers 754 and 756 and the Reverse-link User unit 726 will provide switching operations for the cellular receive operation of the User unit 702. Also, the RF switch 712 connected to antennas 704 and 706 and the duplex filter 714, will provide switching operations for the U-NII band transmit/receive operation of the User unit 702. The duplex filters 754 and 756 are also connected to antennas 734 and 736 on one side, and the Complex-Weight unit 748 on the other side, as well as the RF switch unit 732. The complex-weight unit 748 is connected to power-splitter (hybrid combiner) 745 and the micro-controller 728. The power-splitter (hybrid combiner) 745 is connected to Forward-link User unit 724 via the directional coupler 746. All directional couplers in this invention may be 17dB directional couplers. Also, the duplex filter 714 is connected to Forward-link User unit 724 via the directional couplers 740 and 718, and also connected to Reverse-link User unit 726. It is possible, and is more desirable, to place the Forward-link User unit 328 receiver 210 internal LNA, before the directional couplers 718 and 740 in diagram 700.

A calibration signal generator/transmitter unit 744 is coupled to the forward-link transmitter path of the User unit 702, via the directional coupler 746. The unit 744 will provide a channel-sounding signal, which is used to establish the complex channel characteristics which exist between the User unit 702 antennas 734 and 736, and the input to the calibration signal receiver 742. The channel-sounding signal generated by unit 744 is transmitted via the complex-weight unit 748 and the diversity antennas 734 and 736 with a maximum transmit level, which is substantially below any expected signal level

from cellular network (e.g. 20 dB below the minimum expected cellular signal level). The combined transmitted channel-sounding signal level, and the processing gain used in the calibration signal receiver unit 742 has to be equal to (or less than) the Down-link Gain Margin (dg_{dl}). The channel-sounding signal generated by unit 744 is a direct-sequence spread spectrum signal modulated by a known Pseudo Random (PN) code with a known code phase (referred to hereafter as "own code" phase) and with a chipping rate comparable to the forward and reverse links of the User unit 702 and Network unit 602 (in figure 600) operating bandwidths (e.g. 5Mchips/s for 5MHz bandwidth) and a minimum code length to provide the required processing gain, which has also a code length (in time) longer than the maximum expected path delay (a code length of 1000 chips is adequate for most scenarios). The channel-sounding signal can be transmitted continuously or transmitted only when it is required. The code phases have to be selected such that the minimum code phase difference is larger than the maximum expected path delay (measured in multiple number of chips), and after that the code phases should be multiple integer of the minimum code phase. The calibration signal receiver unit 742 which is coupled to the forward-link receive path of the User unit 702, by directional coupler 740, using the known PN code and the transmit code phase is then capable of detecting and demodulating the channel-sounding signal transmitted by unit 744, which has entered the reverse-link path via the mentioned closed-loop mechanism that exists between the User unit 702 and the Network unit 602 in figure 600 (502 in figure 500). The calibration signal receiver unit 742 is capable of establishing the received signal strength and phase (complex channel impulse response that exists between the User unit 702 combined outputs of antennas 734 and 736, and the input to the calibration signal receiver 742), either by correlation operation, similar to a RAKE receiver path searcher, or by matrix inversion operation on an appropriate block of sampled received signal, as discussed in the appendix A. The calibration signal receiver unit 742 includes many sub-units, including a frequency converter, to return the calibration signal to base-band frequencies and other units such as A/D converters and base-band processors to perform the necessary base-band algorithms, which are not shown in the diagram. The PN code phase can be assigned uniquely, or drawn according to a random algorithm, such that the probability of two units having the same code phase can be very low. Other code offset assignment strategies are also possible, such as dynamic assignment, where the code offset is selected, if no such offset was detected in that geographical area. This feature will enable the calibration signal receiver 742 to be able to scan and receive "other code" phases, and hence establishing if there is any other signal coupling to or from other units, that may be operating in the same geographical area. Further, more than one code phases can be used, to establish the mentioned complex channel impulse response, so that the probability of detection by other systems is increased. This PN code used for the channel-sounding signal can be modulated with information about the identity of the User unit 702. The carrier frequency of the transmitted channel-sounding signal is preferred to be at the operating cellular frequency band. However, it is also possible to use carrier frequencies in other bands, such as ISM band at 2.4GHz, for the transmission of the channel-sounding signal. In this alternative scenario, the calibration signal generator and transmitter 744 carrier frequency is placed as near as possible to the operating frequency band. The chipping rate and the transmit power of the channel-sounding signal PN code has to be such that the channel-sounding signal complies with the FCC 47 CFR Part-15

rules. Although the mentioned ISM band is not the same as the cellular operating band, nevertheless, it is close enough to enable the system to converge the spatial algorithm weights, to establish the weights W_0 and W_1, used in the complex-weight unit 748. Any antenna and propagation differences in average signal power and antenna behavior, between the ISM and cellular operating bands, can be investigated in the design phase and taken into account in the final system design.

The Reference frequency receiver unit 716, which is capable of receiving the transmitted signal generated by the equipment ID and reference frequency unit 624 in figure 600, is connected to the directional coupler 718. This receiver is capable of extracting the reference frequency and the ID code transmitted by the Network unit 602 equipment ID and reference frequency generator 624. The extracted reference frequency is then used to provide a reference local oscillator 722. The directional coupler 718 is connected to the Forward-link User unit 724. Reverse-link User unit 726 is connected to duplex filter 714. The reference signal and the local oscillator unit 722 can alternatively be based on the control link unit 720 oscillator, if this unit is capable of locking to the received signal carrier frequency, which has been transmitted by control link unit 628 of the Network unit 602.

The Control Link unit 720 is a radio link between the two, Network unit 602 and the User unit 702. It may be a proprietary link that operates in one of the unlicensed band of frequencies, or may be a standard wireless link such as 802.11b, 802.11a or Bluetooth, designed to operate in unlicensed band. The control link unit 720 is connected to micro-controller unit 728, and is able to communicate with this unit through an appropriate interface. The control link unit 720 is also connected to antennas 708 and 710 for transmission and reception of the control signals. Note that provided that the antenna bandwidth and operating frequency allow, with minor modifications to unit 702, antenna units 704 and 706 can also be used for the control link unit 720 operations.

Micro-controller unit 728 is a simple micro-processor such as ARM7 or ARM9 with all the appropriate memory and interfaces. The micro-controller unit 728 is controlling the operation of the User unit 702, and may perform some additional signal conditioning and processing such as signal level averaging and estimation and adaptive algorithms such as LMS and RLS where required. Some of the task of the micro-controller unit 728 is to set the operating bandwidth and set the weights W_0 and W_1, to communicate with and control the Network unit 602 in figure 600, via the control link unit 720, to control and communicate with the calibration signal generator and transmitter 744 and calibration signal receiver 742, to operate the switching for the receiver antenna diversity and monitor the correct operation of the User unit 702. Other tasks of the micro-controller 728 are discussed later by way of an example given in figures 900(a), 900(b), 900(c) and 910. Micro-controller unit 728 is connected to units 720, 742, 744, 716, 748, 726, and 724, as well as the RF switches 732 and 712. The micro-controller 728, using the complex channel impulse response at the output of the calibration signal receiver unit 742, and using LMS (or RLS or QR-RLS or QR decomposition) computes the optimum values of the complex weights, W_0 and W_1, such that the received complex channel impulse response at the output of the calibration signal receiver unit 742, is minimized in

magnitude. With such transmit weights arrangement, the RF isolation (for down-link frequencies) between the User unit 702 and the Network unit 602 is adapted within the propagation channel, allowing the maximum possible overall ERP (Effective Radiated Power) from antennas 734 and 736, and hence the maximum coverage footprint.

Units 720, 726, 724, 742, 744 and 728 are all connected to local oscillator unit 722, and derive their clock and reference frequencies from the local oscillator 722 signal. A simple user interface unit 721, which can be a keypad or simple dipswitch, is connected to micro-controller unit 728. The Network unit 702 has a unique "identity code", which can be set by the user interface unit 721, which is known to the micro-controller unit 728 and can be communicated to the Network unit 602 micro-controller unit 626, or any other Network or User units that may be within the operating range of User unit 702.

Techniques, such as the use of vertical polarization for antenna units 610 and 608, and horizontal polarization for antennas 734 and 736 can further improve the system performance. It is also possible to improve system performance by the use of directional antennas, as in conventional booster and repeater systems.

It is also possible to transmit the unique Network unit 602 identity code, and optionally device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded (protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the Network unit 602. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the Network unit 602. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station requires base station receiver modifications, but does not affect the normal operation of the cellular link.

An example of the above system operation is shown in figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c) and 910. Figures 800(a), 800(b), 800(c) and 820 are the system operation flow diagrams for the Network unit 602 and figures 900(a), 900(b), 900(c) and 910 are the flow diagrams for the User unit 702. The examples do not include all the possible functionalities for the complete operation of the Network unit 602 and User unit 702. The examples are used to show the minimum control flows that are required for the most basic operation of the Network unit 602 and the User unit 702. There are mainly two independent control flow operations that are executed concurrently on the micro-controller 626. The first control-flow is to establish normal operation of the booster, with the second one to monitor the correct operation of the control link between

the Network unit 602 and the User unit 702. On "power-up" or "reset" or a "Stop" instruction, the Network unit 602 sets the complex-weight unit 648 weights, W_0 and W_1 , to "Initial" value by default. The "Initial" values (of the weights) are those that allow minimum power radiation from the two antennas 608 and 610, with no phase differential between the two radiated fields, i.e. broadside radiation. On "power-up" or "reset" instruction of the Network unit 602 (assuming that the "identity code" of the interested User unit 702 is known by or pre-entered into the Network unit 602 via the user interface unit 627), the micro-controller unit 626 will start the control-flow (step 802) in figure 800(a). The micro-controller unit 626 instructs the control link unit 628 to establish link with the User Unit 702 (step 804). The control link unit 628, using the appropriate protocols, will continue trying to establish a communication link with the control unit 720 of the User unit 702 until such link is established (step 806). The micro-controller unit 626 will select the desired U-NII band of operation (step 808) and instruct the calibration signal receiver unit 620 to try to receive all the possible code offsets (step 810), in this frequency band. This will ensure that there are no signal paths from other User units operational in the immediate area into the Network unit 602, and help select an unused code offset and transmission channel. If an unintended signal path exists between the Network unit 602 and other operating User units (step 812), depending on the severity of the said coupling path and the strength of the "other units" received channel-sounding signal(s) strength, several different actions can be taken, after a comparison of the received signal SNR with threshold SNR (SNR_{th}), which is based on maximum allowed interference + noise level for acceptable performance (step 814):

1) If the strength of the received channel-sounding signal(s) from other User unit(s) is below the threshold (SNR_{th}), indicating NO interference with the operation of the Network unit 602 and User unit 702, the micro-controller 626 proceeds as normal to step 824.

2) If the strength of the received channel-sounding signal(s) from other User unit(s) is above the threshold (SNR_{th}), indicating interference with the operation of the Network unit 602 and User unit 702, the Network unit 602 will try to select another U-NII frequency band of operation (step 816), and if more U-NII operating band is available, steps 808, 810, and 812 are repeated (step 816).

3) If the strength of the received channel-sounding signal(s) from other User units is above the threshold (SNR_{th}), indicating interference with the operation of the Network unit 602 and User unit 702, and no new clean U-NII operating frequency band can be found, the Network unit 602 will issue an appropriate error signal (step 818) and instruct User unit 720 to "stop" operation (step 820), and the Network unit 602 will also "stop" operation (step 822).

After the successful establishment of the control link between the Network unit 602 and the User unit 702, and successful selection of an U-NII operation band, micro-controller 626, via the control link unit 628, instructs the User unit 702 to scan for all possible code offsets in the selected U-NII band of frequencies (step 824), after which micro-controller 626 will wait for the scan report from User unit 702. If there are any other unit(s)

operating nearby that are detected by the User unit 702, micro-controller 626 will go to step 816, look for another U-NII band of frequencies, and will follow the subsequent steps as described above. If no other operational unit(s) is (are) detected by the User unit 702, the micro-controller 626 will continue to step 828 (Fig. 800 (b)), where it selects an unused Code-Offset ("own code" phase). The micro-controller 626, via the control link unit 628, informs the User unit 702 of the selected "own code" phase (step 830). After entering the network unit 602 into "channel-sounding" mode (step 832), micro-controller 626, via the control link unit 628, instructs User unit 702 to enter the "channel-sounding" as well (step 834). In "channel-sounding" mode the diversity switches 612 and 634 in Network unit 602, and 732 and 712 in User unit 702, are kept in the current position (i.e. not switching). Micro-controller 626, via the control link unit 628, instructs the User unit 702 to commence with channel-sounding operation (step 836). Micro-controller 626 sets the complex-weight unit 648 weights W_0 and W_1 to the "Initial" value (step 838). Micro-controller 626 instructs calibration signal generator and transmitter unit 622 to commence transmission with the specified "own code" phase (step 840). The micro-controller 626 will also instruct the calibration signal receiver unit 620 to try to receive the channel-sounding signal for the above mentioned code offset, used by the transmitter unit 622 (step 842). If no substantial channel-sounding signal is detected with the specified set of weights of the complex-weight unit 648 (step 844), and Up-link System Link Gain, $\boldsymbol{G_{ul}}$, is less than the specified maximum allowed system gain (step 846), micro-controller 626 will modify and issue new weight values to complex-weight unit 648, such that the transmit power of the channel-sounding signal is increased by a predetermined step size, $\boldsymbol{dG}$, while keeping the relative phases of the weights (W_0 and W_1) the same (step 848). Steps 842, 844, 846 and 848 are repeated until a substantial channel-sounding signal is detected, or the maximum allowed system gain is reached. If maximum allowed system gain is reached, the most recent weights are kept (frozen) as the most optimum weights for normal operation (step 850). If maximum allowed system gain is not reached, and there is substantial channel-sounding signal at the output of the calibration signal receiver 620, an adaptive convergence algorithm such as LMS is used to further modify the weights (W_0 and W_1), such that the channel-sounding signal power is minimized (step 852). The new weights are issued to the complex-weight unit 648 for transmission of the channel-sounding signal (step 854). If the weights are sufficiently converged (step 856), the control-flow will proceed to next step, otherwise, steps 840 to 856 are repeated. After the successful convergence of the Network unit 602 weights (W_0 and W_1), micro-controller 626 will check, and if necessary wait, for the User unit 702 weights convergence confirmation (steps 858 and 860). After the successful convergence of both Network unit 602 and User unit 702 weights (W_0 and W_1), micro-controller 626 instructs the user unit 702 to exit the channel-sounding mode (step 862), and it will exit the channel sounding mode itself (step 864). Micro-controller 626 instructs the calibration signal receiver 620 to continue to receive the channel-sounding signal transmitted by the calibration signal transmitter 622 (step 866). If the safe average channel-sounding signal power level is exceeded for a substantial amount of time (step 868), the micro-controller 626 control flow will go to step 832, and start the channel-sounding processes again. If the average channel-sounding signal power level is within the expected range, the calibration signal receiver 620 is instructed to receive and detect channel-sounding signals with all other possible code offsets (step 870). If no channel-sounding signal with

substantial average signal power level is detected, the micro-controller 626 will check to see if there are any reported messages (problems) from the User unit 702 (step 874), and if there are none, it will return to step 866. If a channel-sounding signal with substantial average signal power level is detected, or there is a problem reported by the User unit 702, the micro-controller 626 will go to step 802 (step 876) and start the whole control flow process again. In order to speed up the search and detection of other code offsets, it is also possible to have two (or more) replicas of the calibration signal receiver 620, such that the "own code" detection can be continuous and uninterrupted, while other receiver replicas can scan for "other code" offsets.

The second control-flow operation is shown in figure 820. The second operation checks the quality and performance of the control links of the control units 628 and 720 operation, by monitoring such quantities as BER, SNR, background noise and interference (step 880). If the operation of the link is not satisfactory (step 882), an error signal is flagged (step 884), and the complex-weight unit 648 weights, W_0 and W_1, are set to the "Initial" value (step 886), and the User unit 702 is instructed to do the same (Step 888), and finally the micro-controller 626 will go back to step 802 (step 890).

Figures 900(a), 900(b), 900(c) and 910 are the system operation flow diagrams for the User unit 702. There are mainly two independent control flow operations that are executed concurrently on the micro-controller 728. The first control-flow is to establish normal operation of the booster, with the second one to monitor the correct operation of the control link between the User unit 702 and the Network unit 602. On "power-up" or "reset" or a "Stop" instruction, the User unit 702 sets the complex-weight unit 748 weights, W_0 and W_1, to "Initial" value by default. The "Initial" values (of the weights) are those that allow minimum power radiation from the two antennas 734 and 736, with no phase differential between the two radiated fields, i.e. broadside radiation. On "power-up" or "reset" instruction of the User unit 702 (assuming that the "identity code" of the interested Network unit 602 is known by or pre-entered into the User unit 702 via the user interface unit 721), the micro-controller unit 728 will start the control-flow (step 902) in figure 900(a). The micro-controller unit 728 instructs the control link unit 720 to establish link with the Network Unit 602 (step 904). The control link unit 720, using the appropriate protocols, will continue trying to establish a communication link with the control unit 628 of the Network unit 602 until such link is established (step 906). The micro-controller unit 728 will try to detect instruction messages from the Network unit 602 (step 908) and will continue to do so until an instruction is detected (step 910). On the receipt of the first instruction from the Network unit 602, micro-controller unit 728 will try to determine the instruction content. First instruction to be tested for is the "Stop" instruction (step 912). If the instruction is "Stop", the micro-controller unit 728 sets the complex-weight unit 648 weights, W_0 and W_1, to the "Initial" value (step 914) and continues to detect new instructions. If the instruction is "Scan for all code offset in the specified U-NII band" (step 916), the micro-controller unit 728 instructs the Calibration signal receiver unit 742 to scan for all the possible code offsets (step 918), in the specified frequency band. This will ensure that there are no signal paths from other Network units operational in the immediate area into the User unit 702, and help select an

unused code offset and transmission channel. User unit 702, via the control link 720 informs the Network unit 602 of the scan results for all the code offsets with significant signal level (step 920) and waits for new instruction. At this stage, the micro-controller unit 728 awaits new instruction from Network unit 602, by going to step 908. If the new instruction is "Enter the channel sounding mode" (step 922), micro-controller unit 728 enters this mode by setting the diversity switches 732 and 712 to a fixed state (i.e. not switching) (step 924). Micro-controller 728 sets the complex-weight unit 748 weights, W_0 and W_1, to the "Initial" value (step 926). Micro-controller 728 instructs calibration signal generator and transmitter unit 744 to commence transmission with the specified "own code" phase (step 928). The micro-controller 728 will also instruct the calibration signal receiver unit 742 to try to receive the channel-sounding signal for the above mentioned code offset, used by the transmitter unit 744 (step 930). If no substantial channel-sounding signal is detected with the specified set of weights of the complex-weight unit 748, and Down-link System Link Gain, G_{dl}, is less than the specified maximum allowed system gain (step 934), micro-controller 728 will modify and issue new weight values to complex-weight unit 748, such that the transmit power of the channel-sounding signal is increased by a predetermined step size, ***dG***, while keeping the relative phases of the weights (W_0 and W_1) the same (step 936). Steps 930, 932, 934 and 936 are repeated until a substantial channel-sounding signal is detected, or the maximum allowed system gain is reached. If maximum allowed system gain is reached, the most recent weights are kept (frozen) as the most optimum weights for normal operation (step 944). If maximum allowed system gain is not reached, and there is substantial channel-sounding signal at the output of the calibration signal receiver 742, an adaptive convergence algorithm such as LMS is used to further modify the weights (W_0 and W_1), such that the channel-sounding signal power is minimized (step 938). The new weights are issued to the complex-weight unit 748 for transmission of the channel-sounding signal (step 940). If the weights are sufficiently converged, the control-flow will proceed to next step, otherwise, steps 928 to 942 are repeated. After the successful convergence of the User unit 702 weights (W_0 and W_1), micro-controller unit 728 will inform the Network unit 602 and confirms the convergence of the weights (step 946). At this stage, micro-controller unit 728 awaits instruction to exit the channel-sounding mode (steps 948 & 950). After the detection of the instruction "Exit channel-sounding mode", micro-controller unit 728 exits this mode (step 952) and instructs the calibration signal receiver 742 to continue to receive the channel-sounding signal transmitted by the calibration signal transmitter 744 (step 954). If the safe average channel-sounding signal power level is exceeded for a substantial amount of time (step 956), the micro-controller 728 will set the complex-weight unit 748 weights, W_0 and W_1, to the "Initial" value (step 926), and inform the Network unit 602 (step 964), after which it returns to step 908. If the average channel-sounding signal power level is within the expected range, the calibration signal receiver 742 is instructed to receive and detect channel-sounding signals with all other possible code offsets (step 958). If a channel-sounding signal with substantial average signal power level is detected, the micro-controller 728 will go to step 962 (step 960). If no other channel-sounding signal with substantial average signal power level is detected, the micro-controller 728 will return to step 908. In order to speed up the search and detection of other code offsets, it is also possible to have two (or more) replicas of the

calibration signal receiver unit 620, such that the "own code" detection can be continuous and uninterrupted, while other receiver replicas can scan for "other code" offsets.

The second control-flow operation is shown in figure 910. The second operation checks the quality and performance of the control links of the control units 720 and 628 operation, by monitoring such quantities as BER, SNR, background noise and interference (step 970). If the operation of the link is not satisfactory (step 972), an error signal is flagged (step 974), and the complex-weight unit 748 weights, W_0 and W_1, are set to the "Initial" value (step 976), and the Network unit 602 is informed (step 977) before the micro-controller 728 returns to step 902 (step 978).

As already mentioned, the above description is only an example of how the system may be implemented, and it is appreciated that it is not the only possible method and solution and not all the required control signaling is covered. There are several points that need to be noted.

1- It is possible for the Network unit 602 to control several User units, such as the User unit 702. In such setups, the example control flows, shown in figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c) and 910 need some modifications such that the Network Unit 602 can initialize each User unit independently at first, and together in a final step. It is also desirable, in a scenario with several User units such as 702, that the Network unit 602 weights are converged for the User unit that has the minimum Up-link System Path Loss, $\boldsymbol{PL_{ul}}$, with the Network unit 602. Therefore each User unit (702) in a booster network may require a unique code phase.

2- Another modification that is required for multi User unit (several User units 702) operation is that the final weights convergence of all the units in a booster network (Network and User units) should be carried out with all User units, under the control of the Network unit 602, active in the channel-sounding operation, such that combined signal power levels do not exceed the safe limit. If combined signal from the User Units exceeds the acceptable level for either of the reverse or forward system links, the appropriate weights have to be modified, in iterative step increments, to such level that the maximum allowed system link gains of the forward and the reverse links are met.

3- Although the signal path in both the Network unit 602 and the User unit 702, in the forward link direction, always needs to be active, in order to boost the beacon (BCCH in GSM) transmissions of the base stations, the reverse-link signal path of the Network unit 602 and the User unit 702 need not to be active, unless a substantial signal level is detected, based on the presence of uplink signal (i.e. "gated"). Care has to be taken that the reverse-link "gated" operation mentioned above, does not interfere with the channel-sounding signal path and mechanism involving the units 622 and 620. Therefore, the "gated" operation has to become

continuous operation (as discussed in the main description) during the channel-sounding process, with channel sounding carried out on regular bases.

4- With certain modifications in the hardware and the control software, it is possible to merge the Network unit 602 and the User unit 702 into a single unit, connected "back-to-back". The design and operation of the back-to-back option is shown in figure 2250 and discussed later.

5- It is also possible to transmit the unique Network unit 602 identity code, and optionally device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded (protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the Network unit 602. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the Network unit 602. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station requires base station receiver modifications, but does not affect the normal operation of the cellular link.

6- It is also possible and desirable to include in the system design, Closed-loop power control mechanisms, between the Network unit 602 and User unit 702 for the unlicensed band (U-NII) operation, both in forward and reverse links of the system. Such closed-loop power control mechanism can be based on very low-rate (e.g. 10 Hz) differential or absolute power control commands (based on received signal power), to increase or reduce the U-NII band transmission powers, such that only sufficient power is transmitted from the antennas 636, 638 on the Network unit 602 side, and antennas 704 and 706 on the User unit 702 side, for correct operation. This may require variable gain amplifiers for the transmission of the U-NII band, both in the Network unit 602 and the User unit 702. The closed-loop power control messages can be exchanged between the Network unit 602 and the User unit 702, via the control link units 628 and 720 in forward and reverse-links.

7- On the Network unit 602 side, once the complex-weight unit 648 weights, W_0 and W_1 are converged, it is possible to superimpose spatial dither on the antenna radiation pattern, such that the multipath standing waves patterns are sufficiently disturbed to provide some diversity gain on the Up-link. It is also possible to converge a second set of weights that keep the spatial position of the "nulls", while changing the radiation pattern sufficiently, to provide antenna radiation pattern diversity. Such weights can be converged by first performing direction finding (such as DFT) on the original weights to identify the 'Null" position, and

forming new weights using algorithms such as Minimum-Variance Linear-Constraint Beam-forming algorithms (MVLCBF), with the constraint being the position of the spatial "Null". Repeated switching between the two sets of weights will provide antenna pattern diversity gain on the up-link. The same is applicable to the User unit 702 for Down-link path.

8- In the above example of the Network unit 602 and the User unit 702, only two sets of complex weights W_0 and W_1, are used in the complex-weight units 648 and 748, as two diversity antennas are readily available at both units. However, it is appreciated that both in the Network unit 602 and in the User unit 702, more than two antennas and hence more than two weights can be used, based on the above description with minor modifications.

9- Although, the complex-weight units 648 (in the Network unit 602) and 748 (in the Network unit 702) are for transmitter beam-forming, it is possible to use similar complex weight units at the input to the receivers of the Forward-link Network unit 604 (in the Network unit 602) and Reverse-link User unit 726 (in the Network unit 702) so that receiver beam-forming can also be performed. The receiver weight convergence can be based on similar procedure as the transmitter one, with only minor changes.

10- It is possible to converge the weights (W_0 and W_1) of the complex-weight units 648 (in the Network unit 602) and 748 (in the Network unit 702), with the Reverse-link Network unit 606 (in the Network unit 602) and Forward-link User unit 724 (in the Network unit 702) completely "OFF" (i.e. not functional), such that cellular signals are not repeated (transmitted). This will allow the convergence of the weights (W_0 and W_1) of the complex-weight units 648 (in the Network unit 602) and 748 (in the Network unit 702) first, before the start of the booster normal operation.

The above discussion is applicable to all the different analogue implementations of all the various boosters discussed in this invention.

2.2 Digital Implementation Example

Figure 1000 shows an example of digital implementation of the Network unit 602 (labeled 1002 in figure 1000), which is placed where good signal coverage exists, indoor or outdoors. Two antennas 1004 and 1006 are used for antenna diversity for the cellular band transmitter and receiver of the Network unit 1002. Also two antennas 1036 and 1038 are used for antenna diversity of the U-NII band operation of the Network unit 1002. Although, any diversity-combining scheme such as Maximal Ratio Combining, etc. can be used for the receiver chain, and transmit diversity schemes such as random phase change in one or both antennas for the transmitter chain, a simple scheme that is based on antenna switched diversity is suggested here. The switching can be continuous or based on received signal power level. Therefore, the RF switch 1008 connected to duplexers 1007 and 1010 and the LNA unit 1012 will provide switching operations for the cellular receive operation of the Network unit 1002. Also, the RF switch 1032 connected to antennas 1036 and 1038 and the duplex filter 1034 will provide switching operations for the U-NII band transmit/receive operation of the Network unit 1002. The duplex filters 1007 and 1010 are also connected to antennas 1004 and 1006 on one side, and the Complex-Weight unit 1072 on the other side, as well as the RF switch unit 1008. The complex-weight unit 1072 is connected to power-splitter (hybrid combiner) 1070 and the micro-controller 1060. The power-splitter (hybrid combiner) 1070 is connected to power amplifier unit 1054 via the directional coupler 1056. All the directional couplers in this invention may be 17dB directional couplers. LNA 1012 is connected to the frequency converter unit 1014. Frequency converter 1014 is connected to Automatic Gain Control (AGC) unit 1018. The frequency converter 1014 converts the frequency band of the incoming signal from the cellular band to baseband, or "near baseband" frequency band. The frequency converter unit 1014 includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 1014 is set by micro-controller unit 1060. The AGC unit 1018 is connected to Analogue to Digital Converter (AD/C) unit 1020 and the Signal Conditioning (SC) unit 1022. The AGC 1018 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 1020. If included, care has to be taken in the design and operation of this unit (1018), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 1018. Also care has to be taken, so that the gain contribution of the AGC unit 1018 is compensated for in the final Down-link System Link Gain, G_{dl} calculations, or alternatively the gain value of the AGC 1018 is compensated for in the SC unit 1022. If AGC unit 1018 is used in Network unit 1002 and the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If the AGC unit 1018 is not included, the AD/C unit 1020 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 1020 is connected to the Signal Conditioning unit 1022. The Signal Conditioning unit 1022 performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, insertion of reference frequency, signal level estimation, AGC algorithm, WLAN transmitter algorithms, and any other features

that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link cellular or PCS or desired frequency spectrum. The Signal Conditioning unit 1022 clock frequency is derived from a local reference frequency unit 1070 and provided by clock unit 1024. Depending on the system parameters and the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 1022 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 1022 includes all the required interfaces and memory. The Signal Conditioning unit 1022 is connected to Digital to Analogue Converter (DA/C) unit 1026. The DA/C unit 1026 includes the required post filtering that is required after the digital to analogue conversion. The DA/C unit 1026 is connected to frequency converter unit 1028. Frequency converter unit 1028 up-converts the frequencies of the input signal to the desired portion of U-NII band of frequencies. The frequency converter unit 1028 includes all the required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 1028 is set by micro-controller unit 1060. Therefore, Dynamic Channel Allocation (DCA) algorithm can be used to select the best operating frequency band. The frequency converter unit 1028 is connected to the variable gain amplifier unit 1030. The gain of this amplifier 1030 is set by the micro-controller unit 1060, and can be set to maximum allowed power for transmission in U-NII band. The variable gain amplifier unit 1030 is connected to Duplex filter 1034. The duplex filter 1034 is connected to reverse-link LNA 1040 and the VG amplifier 1030. LNA 1040 is connected to the frequency converter unit 1042. Frequency converter unit 1042 is connected to the directional coupler unit 1041. The frequency converter 1042 converts the frequency band of the incoming signal from the U-NII band to baseband, or "near baseband" frequency band. The frequency converter unit 1042 includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 1042 is set by micro-controller unit 1060. Directional coupler unit 1041 is connected to Automatic Gain Control (AGC) unit 1044, and the calibration signal receiver unit 1016. The AGC unit 1044 is connected to Analogue to Digital Converter (AD/C) unit 1046 and the Signal Conditioning unit 1048. The AGC 1044 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 1046. If included, care has to be taken in the design and operation of this unit (1044), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 1044. Also, care has to be taken, so that the gain contribution of the AGC unit 1044 is compensated for in the final Up-link System Link Gain, G_{ul} calculations, or alternatively the gain value of the AGC 1044 is compensated for in the SC unit 1048. If AGC unit 1044 is used in Network unit 1002 and the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If the AGC unit 1044 is not included, the AD/C unit 1046 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 1046 is connected to the Signal Conditioning unit 1048. The Signal Conditioning unit 1048

performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, signal calibration receiver, signal level estimation, AGC algorithm, WLAN receiver algorithms and any other features that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link U-NII or any desired frequency spectrum. The Signal Conditioning unit 1048 clock frequency is derived from a local reference frequency unit 1070 and provided by clock unit 1024. Depending on the system parameters such as the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 1048 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 1048 includes all the required interfaces and memory. The Signal Conditioning unit 1048 is connected to Digital to Analogue Converter (DA/C) unit 1050. The DA/C unit 1050 is connected to frequency converter unit 1052. The DA/C unit 1050 includes the required post filtering that is required after the digital to analogue conversion. Frequency converter unit 1052 up-converts the frequencies of the input signal to the desired portion of cellular or PCS band of frequencies. The frequency converter unit 1052 includes all required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 1052 is set by micro-controller unit 1060. The frequency converter unit 1052 is connected to the power amplifier unit 1054. The power amplifier unit 1054 is connected to directional coupler 1056.

A calibration signal generator/transmitter unit 1058 is coupled to the reverse-link transmitter path of the Network unit 1002, via the directional coupler 1056. The unit 1058 will provide a channel-sounding signal, which is used to establish the complex channel characteristics which exist between the Network unit 1002 antennas 1004 and 1006, and the input to the calibration signal receiver 1016. The channel-sounding signal generated by unit 1058 is transmitted via the complex-weight unit 1072 and the diversity antennas 1004 and 1006 with a maximum transmit level, which is substantially below any expected signal level from cellular network (e.g. 20 dB below the minimum expected cellular signal level). The combined transmitted channel-sounding signal level, and the processing gain used in the calibration signal receiver unit 1016 has to be equal to (or less than) the Up-link Gain Margin (dg_{ul}). The channel-sounding signal generated by unit 1058 is a direct-sequence spread spectrum signal modulated by a known Pseudo Random (PN) code with a known code phase (referred to hereafter as "own code" phase) and with a chipping rate comparable to the forward and reverse links of the Network unit 1002 and User unit 2002 (in figure 2000) operating bandwidths (e.g. 5Mchips/s for 5MHz bandwidth) and a minimum code length to provide the required processing gain, which has also a code length (in time) longer than the maximum expected path delay (a code length of 1000 chips is adequate for most scenarios). The channel-sounding signal can be transmitted continuously or transmitted only when it is required. The code phases have to be selected such that the minimum code phase difference is larger than the maximum expected path delay (measured in multiple number of chips), and after that the code phases should be multiple integer of the minimum code phase. The calibration signal receiver unit 1016 which is coupled to the reverse-link receive path of the Network unit

1002, by directional coupler 1041, using the known PN code and the transmit code phase is then capable of detecting and demodulating the channel-sounding signal transmitted by unit 1058, which has entered the reverse-link path via the mentioned closed-loop mechanism that exists between the Network unit 1002 and the User unit 2002 in figure 2000. The calibration signal receiver unit 1016 is capable of establishing the received signal strength and phase (complex channel impulse response that exists between the Network unit 1002 combined outputs of antennas 1004 and 1006, and the input to the calibration signal receiver 1016), either by correlation operation, similar to a RAKE receiver path searcher, or by matrix inversion operation on an appropriate block of sampled received signal, as discussed in the appendix A. The calibration signal receiver unit 1016 includes many sub-units, including a frequency converter, to return the calibration signal to base-band frequencies and other units such as A/D converters and base-band processors to perform the necessary base-band algorithms, which are not shown in the diagram. The PN code phase can be assigned uniquely, or drawn according to a random algorithm, such that the probability of two units having the same code phase can be very low. Other code offset assignment strategies are also possible, such as dynamic assignment, where the code offset is selected, if no such offset was detected in that geographical area. This feature will enable the calibration signal receiver 1016 to be able to scan and receive "other code" phases, and hence establishing if there is any other signal coupling to or from other units, that may be operating in the same geographical area. Further, more than one code phases can be used, to establish the mentioned complex channel impulse response, so that the probability of detection by other systems is increased. This PN code used for the channel-sounding signal can be modulated with information about the identity of the Network unit 1002. The carrier frequency of the transmitted channel-sounding signal is preferred to be at the operating cellular frequency band. However, it is also possible to use carrier frequencies in other bands, such as ISM band at 2.4GHz, for the transmission of the channel-sounding signal. In this alternative scenario, the calibration signal generator and transmitter 1058 carrier frequency is placed as near as possible to the operating frequency band. The chipping rate and the transmit power of the channel-sounding signal PN code has to be such that the channel-sounding signal complies with the FCC 47 CFR Part-15 rules. Although the mentioned ISM band is not the same as the cellular operating band, nevertheless, it is close enough to enable the system to converge the spatial algorithm weights, to establish the weights W_0 and W_1, used in the complex-weight unit 1072. Any antenna and propagation differences in average signal power and antenna behavior, between the ISM and cellular operating bands, can be investigated in the design phase and taken into account in the final system design.

The calibration transmitter unit 1058 and the calibration receiver unit 1016 baseband functions, as well as the complex-weight unit 1072 (for this inclusion, two amplifiers such as 1054 are required before the duplex filters 1007 and 1010) can be integrated and supported by the Signal Conditioning unit 1048. In this example, the calibration signal generator and transmitter unit 1058 and the calibration signal receiver 1016 are both in the Network unit 1002. However, it is understood that both, or one of the units, calibration signal generator and transmitter unit 1058, and the calibration signal receiver 1016, can also be placed in the User unit 2002, with certain modifications and

considerations. The Equipment ID and reference frequency unit 624 shown in figure 600, in the forward-link path, is now supported by the Signal Conditioning unit 1022 in the digital Network unit 1002, with the description and function remaining the same as the one discussed for unit 624.

The control link unit 1062 is a radio link between the two Network 1002 and the User 2002 (in figure 2000) units. It may be a proprietary link that operates in one of the unlicensed band of frequencies, or may be a standard wireless link such as 802.11b, 802.11a, 802.11g or Bluetooth, designed to operate in the unlicensed band. The control link unit 1062 is connected to micro-controller unit 1060, and is able to communicate with this unit through an appropriate interface. The control link unit 1062 is also connected to antennas 1066 and 1064 for transmission and reception of the control signals. Note that provided that the antenna bandwidth and operating frequency allow, with minor modifications to unit 1002, antenna units 1036 and 1038 can also be used for the control link unit 1062 operations. With minor modifications to unit 1002, and where the selected operating frequencies allow, the baseband functionality of the control link unit 1062 can be included in the Signal Conditioning units 1022 and 1048, with the transmit/receive control link unit 1062 signals multiplexed (in frequency or time) with the transmit/receive signals of the forward and the reverse-link Network unit 1002, that are transmitted and received by antennas 1038 and 1036.

Micro-controller unit 1060 is a simple micro-processor such as ARM7 or ARM9 with all the appropriate memory and interfaces. The micro-controller unit 1060 is controlling the operation of the Network unit 1002, and may perform some additional signal conditioning and processing such as signal level averaging and estimation and adaptive algorithms such as LMS and RLS where required. Some of the task of the micro-controller unit 1060 is to set the operating bandwidth and set the weights W_0 and W_1, to communicate with and control the User unit 2002 in figure 2000, via the control link unit 1062, to control and communicate with the calibration signal generator and transmitter 1058 and to calibration signal receiver 1016, to operate the switching for the receiver antenna diversity and monitor the correct operation of the Network unit 1002 and User unit 2002. Other tasks of the micro-controller 1060 are discussed later by way of an example given in figures 800(a), 800(b), 800(c) and 820. Micro-controller unit 1060 is connected to units 1062, 1016, 1058, 1052, 1048, 1042, 1030, 1028, 1022, 1072 and 1014, as well as the RF switches 1008 and 1032. The micro-controller 1060, using the complex channel impulse response at the output of the calibration signal receiver unit 1016, and using LMS (or RLS or QR-RLS or QR decomposition) computes the optimum values of the complex weights, W_0 and W_1, such that the received complex channel impulse response at the output of the calibration signal receiver unit 1016, is minimized in magnitude. With such transmit weights arrangement, the RF isolation (for up-link frequencies) between the Network unit 1002 and the User unit 2002 is adapted within the propagation channel, allowing the maximum possible overall ERP (Effective Radiated Power) from antennas 1004 and 1006, and hence the maximum coverage footprint.

Units 1062, 1016, 1058, 1052, 1042, 1060, 1028, 1046, 1020, 1024 and 1014 are all connected to local oscillator unit 1070, or derive their clock and reference frequencies

from the local oscillator 1070 signal. A simple user interface unit 1061, which can be a keypad or simple dipswitch, is connected to micro-controller unit 1060. The Network unit 1002 has a unique "identity code", which can be set by the user interface unit 1061, which is known to the micro-controller unit 1060 and can be communicated to the User unit 2002 micro-controller unit 2054, or any other User units that may be within the operating range of Network unit 1002.

Figure 2000 shows an example of digital implementation of the User unit 702 (labeled 2002 in figure 2000), which is placed where good signal coverage does not exist, indoor or outdoors. Two antennas 2034 and 2036 are used for antenna diversity for the cellular band transmitter and receiver of the User unit 2002. Also two antennas 2004 and 2006 are used for antenna diversity of the U-NII band operation of the User unit 2002. Although, any diversity-combining scheme such as Maximal Ratio Combining, etc. can be used for the receiver chain, and transmit diversity schemes such as random phase change in one or both antennas for the transmitter chain, a simple scheme that is based on antenna switched diversity is suggested here. The switching can be continuous or based on received signal power level. Therefore, the RF switch 2032 connected to duplexers 2030 and 2031 and the LNA unit 2038 will provide switching operations for the cellular receive operation of the User unit 2002. Also, the RF switch 2008 connected to antennas 2004 and 2006 and the duplex filter 2010 will provide switching operations for the U-NII band transmit/receive operation of the User unit 2002. The duplex filters 2030 and 2031 are also connected to antennas 2036 and 2034 on one side, and the Complex-Weight unit 2072 on the other side, as well as the RF switch unit 2032. The complex-weight unit 2072 is connected to power-splitter (hybrid combiner) 2070 and the micro-controller 2054. The power-splitter (hybrid combiner) 2070 is connected to power amplifier unit 2028 via the directional coupler 2027. All the directional couplers in this invention may be 17dB directional couplers. LNA 2038 is connected to the frequency converter unit 2040. Frequency converter 2040 is connected to Automatic Gain Control (AGC) unit 2042. The frequency converter 2040 converts the frequency band of the incoming signal from the cellular band to baseband, or "near baseband" frequency band. The frequency converter unit 2040 includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 2040 is set by micro-controller unit 2054. The AGC unit 2042 is connected to Analogue to Digital Converter (AD/C) unit 2044 and the Signal Conditioning (SC) unit 2046. The AGC 2042 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 2044. If included, care has to be taken in the design and operation of this unit (2042), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 2042. Also, care has to be taken, so that the gain contribution of the AGC unit 2042 is compensated for in the final Up-link System Link Gain, G_{ul} calculations, or alternatively the gain value of the AGC 2042 is compensated for in the SC unit 2046. If AGC unit 2042 is used in the User unit 2002 and the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If

the AGC unit 2042 is not included, the AD/C unit 2044 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 2044 is connected to the Signal Conditioning unit 2046. The Signal Conditioning unit 2046 performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, insertion of reference frequency, signal level estimation, AGC algorithm, WLAN transmitter algorithms, and any other features that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link cellular or PCS or desired frequency spectrum. The Signal Conditioning unit 2046 clock frequency is derived from a local reference frequency unit 2023 and provided by clock unit 2022. Depending on the system parameters and the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 2046 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 2046 includes all the required interfaces and memory. The Signal Conditioning unit 2046 is connected to Digital to Analogue Converter (DA/C) unit 2048. The DA/C unit 2048 includes the required post filtering that is required after the digital to analogue conversion. The DA/C unit 2048 is connected to frequency converter unit 2050. Frequency converter unit 2050 up-converts the frequencies of the input signal to the desired portion of U-NII band of frequencies. The frequency converter unit 2050 includes all the required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 2050 is set by micro-controller unit 2054. Therefore, Dynamic Channel Allocation (DCA) algorithm can be used to select the best operating frequency band. The frequency converter unit 2050 is connected to the variable gain amplifier unit 2052. The gain of this amplifier 2052 is set by the micro-controller unit 2054, and can be set to maximum allowed power for transmission in U-NII band. The variable gain amplifier unit 2052 is connected to Duplex filter 2010. The duplex filter 2010 is connected to forward-link LNA 2012 and the VG amplifier 2052. LNA 2012 is connected to the frequency converter unit 2014. Frequency converter unit 2014 is connected to the directional coupler unit 2017. The frequency converter 2014 converts the frequency band of the incoming signal from the U-NII band to baseband, or "near baseband" frequency band. The frequency converter unit 2014 includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 2014 is set by micro-controller unit 2054. Directional coupler unit 2017 is connected to Automatic Gain Control (AGC) unit 2016, and the calibration signal receiver unit 2015. The AGC unit 2016 is connected to Analogue to Digital Converter (AD/C) unit 2018 and the Signal Conditioning unit 2020. The AGC 2016 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 2018. If included, care has to be taken in the design and operation of this unit (2016), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 2016. Also, care has to be taken, so that the gain contribution of the AGC unit 2016 is compensated for in the final Down-link System Link Gain, $\mathbf{G_{dl}}$ calculations, or alternatively the gain value of the AGC 2016 is compensated for in the SC unit 2020. If AGC unit 2016 is used in the User unit 2002 and the unit is designed for CDMA cellular networks, care has to be

taken in selecting the AGC bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If the AGC unit 2016 is not included, the AD/C unit 2018 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 2018 is connected to the Signal Conditioning unit 2020. The Signal Conditioning unit 2020 performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, signal calibration receiver, signal level estimation, AGC algorithm, WLAN receiver algorithms and any other features that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link U-NII or any desired frequency spectrum. The Signal Conditioning unit 2020 clock frequency is derived from clock unit 2022, with the reference frequency provided by unit 2023. Depending on the system parameters such as the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 2020 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 2020 includes all the required interfaces and memory. The Signal Conditioning unit 2020 is connected to Digital to Analogue Converter (DA/C) unit 2024. The DA/C unit 2024 is connected to frequency converter unit 2026. The DA/C unit 2024 includes the required post filtering that is required after the digital to analogue conversion. Frequency converter unit 2026 up-converts the frequencies of the input signal to the desired portion of cellular or PCS band of frequencies. The frequency converter unit 2026 includes all required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 2026 is set by micro-controller unit 2054. The frequency converter unit 2026 is connected to the power amplifier unit 2028. The power amplifier unit 2028 is connected to directional coupler 2027.

A calibration signal generator/transmitter unit 2025 is coupled to the forward-link transmitter path of the User unit 2002, via the directional coupler 2027. The unit 2025 will provide a channel-sounding signal, which is used to establish the complex channel characteristics which exist between the User unit 2002 antennas 2034 and 2036, and the input to the calibration signal receiver 2015. The channel-sounding signal generated by unit 2025 is transmitted via the complex-weight unit 2072 and the diversity antennas 2034 and 2036 with a maximum transmit level, which is substantially below any expected signal level from cellular network (e.g. 20 dB below the minimum expected cellular signal level). The combined transmitted channel-sounding signal level, and the processing gain used in the calibration signal receiver unit 2015 has to be equal to (or less than) the Down-link Gain Margin (***dg_{dl}***). The channel-sounding signal generated by unit 2025 is a direct-sequence spread spectrum signal modulated by a known Pseudo Random (PN) code with a known code phase (referred to hereafter as "own code" phase) and with a chipping rate comparable to the forward and reverse links of the User unit 2002 and Network unit 1002 (in figure 1000) operating bandwidths (e.g. 5Mchips/s for 5MHz bandwidth) and a minimum code length to provide the required processing gain, which has also a code length (in time) longer than the maximum expected path delay (a code

length of 1000 chips is adequate for most scenarios). The channel-sounding signal can be transmitted continuously or transmitted only when it is required. The code phases have to be selected such that the minimum code phase difference is larger than the maximum expected path delay (measured in multiple number of chips), and after that the code phases should be multiple integer of the minimum code phase. The calibration signal receiver unit 2015 which is coupled to the forward-link receive path of the User unit 2002, by directional coupler 2017, using the known PN code and the transmit code phase is then capable of detecting and demodulating the channel-sounding signal transmitted by unit 2025, which has entered the reverse-link path via the mentioned closed-loop mechanism that exists between the User unit 2002 and the Network unit 1002. The calibration signal receiver unit 2015 is capable of establishing the received signal strength and phase (complex channel impulse response that exists between the User unit 2002 combined outputs of antennas 2034 and 2036, and the input to the calibration signal receiver 2015), either by correlation operation, similar to a RAKE receiver path searcher, or by matrix inversion operation on an appropriate block of sampled received signal, as discussed in the appendix A. The calibration signal receiver unit 2015 includes many sub-units, including a frequency converter, to return the calibration signal to base-band frequencies and other units such as A/D converters and base-band processors to perform the necessary base-band algorithms, which are not shown in the diagram. The PN code phase can be assigned uniquely, or drawn according to a random algorithm, such that the probability of two units having the same code phase can be very low. Other code offset assignment strategies are also possible, such as dynamic assignment, where the code offset is selected, if no such offset was detected in that geographical area. This feature will enable the calibration signal receiver 2015 to be able to scan and receive "other code" phases, and hence establishing if there is any other signal coupling to or from other units, that may be operating in the same geographical area. Further, more than one code phases can be used, to establish the mentioned complex channel impulse response, so that the probability of detection by other systems is increased. This PN code used for the channel-sounding signal can be modulated with information about the identity of the User unit 2002. The carrier frequency of the transmitted channel-sounding signal is preferred to be at the operating cellular frequency band. However, it is also possible to use carrier frequencies in other bands, such as ISM band at 2.4GHz, for the transmission of the channel-sounding signal. In this alternative scenario, the calibration signal generator and transmitter 2025 carrier frequency is placed as near as possible to the operating frequency band. The chipping rate and the transmit power of the channel-sounding signal PN code has to be such that the channel-sounding signal complies with the FCC 47 CFR Part-15 rules. Although the mentioned ISM band is not the same as the cellular operating band, nevertheless, it is close enough to enable the system to converge the spatial algorithm weights, to establish the weights W_0 and W_1, used in the complex-weight unit 2072. Any antenna and propagation differences in average signal power and antenna behavior, between the ISM and cellular operating bands, can be investigated in the design phase and taken into account in the final system design.

The calibration transmitter unit 2025 and the calibration receiver unit 2015 baseband functions, as well as the complex-weight unit 2072 (for this inclusion, two amplifiers such as 2028 are required before the duplex filters 2031 and 2030) can be integrated and

supported by the Signal Conditioning unit 2020. In this example, the calibration signal generator and transmitter unit 2025 and the calibration signal receiver 2015 are both in the User unit 2002. However, it is understood that both, or one of the units, calibration signal generator and transmitter unit 2025, and the calibration signal receiver 2015, can also be placed in the Network unit 1002, with certain modifications and considerations. The reference frequency receiver unit 716 shown in figure 700, in the forward-link path, is now supported by the Signal Conditioning unit 2020 in the digital User unit 2002, with the description and function remaining the same as the one discussed for unit 716.

The Control Link unit 2056 is a radio link between the Network unit 1002 and the User unit 2002. It may be a proprietary link that operates in one of the unlicensed band of frequencies, or may be a standard wireless link such as 802.11b, 802.11a or Bluetooth, designed to operate in unlicensed band. The control link unit 2056 is connected to micro-controller unit 2054, and is able to communicate with this unit through an appropriate interface. The control link unit 2056 is also connected to antennas 2058 and 2060 for transmission and reception of the control signals. Note that provided that the antenna bandwidth and operating frequency allow, with minor modifications to unit 2002, antenna units 2004 and 2006 can also be used for the control link unit 2056 operations. Also, with minor modifications to unit 2002, and where the selected operating frequencies allow, the baseband functionality of the control link unit 2056 can be included in the Signal Conditioning units 2046 and 2020, with the transmit/receive control link unit 2056 signals multiplexed (in frequency or time) with the transmit/receive signals of the forward and reverse User unit 2002, that are transmitted and received by antennas 2004 and 2006.

Micro-controller unit 2054 is a simple micro-processor such as ARM7 or ARM9 with all the appropriate memory and interfaces. The micro-controller unit 2054 is controlling the operation of the User unit 2002, and may perform some additional signal conditioning and processing such as signal level averaging and estimation and adaptive algorithms such as LMS and RLS where required. Some of the task of the micro-controller unit 2054 is to set the operating bandwidth and set the weights W_0 and W_1, to communicate with and control the Network unit 1002 in figure 1000, via the control link unit 2056, to control and communicate with the calibration signal generator and transmitter 2025 and to calibration signal receiver 2015, operate the switching for the receiver antenna diversity and monitor the correct operation of the User unit 2002. Other tasks of the micro-controller 2054 are discussed later by way of an example given in figures 900(a), 900(b), 900(c) and 910. Micro-controller unit 2054 is connected to units 2056, 2052, 2050, 2046, 2040, 2026, 2020, 2015, 2025, 2072 and 2014, as well as the RF switches 2032 and 2008. The micro-controller 2054, using the complex channel impulse response at the output of the calibration signal receiver unit 2015, and using LMS (or RLS or QR-RLS or QR decomposition) computes the optimum values of the complex weights, W_0 and W_1, such that the received complex channel impulse response at the output of the calibration signal receiver unit 2015, is minimized in magnitude. With such transmit weights arrangement, the RF isolation (for down-link frequencies) between the User unit 2002 and the Network unit 1002 is adapted within the propagation channel, allowing the

maximum possible overall ERP (Effective Radiated Power) from antennas 2034 and 2036, and hence the maximum coverage footprint.

Units 2056, 2050, 2040, 2026, 2054, 2018, 2044, 2022, 2025, 2015 and 2014 are all connected to local oscillator unit 2023, or derive their clock and reference frequencies from the local oscillator 2023 signal. A simple user interface unit 2055, which can be a keypad or simple dipswitch, is connected to micro-controller unit 2054. The User unit 2002 has a unique "identity code", which can be set by the user interface unit 2055, which is known to the micro-controller unit 2054 and can be communicated to the Network unit 1002 micro-controller unit 1060.

The control-flow description given for figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c) and 910, can also be used for the digital implementation of the Network unit 1002 and User unit 2002, which is discussed above in figures 1000 and 2000.

Considering only the reverse-link operation of the Network unit 1002 and the User unit 2002, as an example, the signals received through antenna units 2034 and 2036, are re-transmitted through the antenna units 1004 and 1006, at a higher signal power. These re-transmitted signals can be received again through the antenna units 2034 and 2036 (and have been termed above as the "Up-link Returned-Signal"), causing a signal return path in the system that may cause instability in the operation of the booster. In the digital implementation of the Network unit 1002 and the User unit 2002, it may be possible to reduce the magnitude of the returned signal (Up-link Returned-Signal) by various signal-processing techniques. The choice, design and effectiveness of a known (or a novel) technique depend on the system parameters and the operating conditions that need to be studied well. Most known multipath mitigation algorithms can also be applied for return signal reduction, however, due to the extremely small propagation delays between the Network unit 1002 and the User unit 2002, and the limited temporal resolution of the system, the conventional algorithms may be practically hard and expensive to implement, at best, or ineffective and detrimental, at worst. Therefore, an example of a novel filtering technique is provided (see the "Novel Channel Filtering" section), where a "deliberate" delay in the re-transmission of the received signal is used, to separate the returned signal (Up-link Returned-Signal), from the original incident signal, at the output of the antenna unit 2034 and 2036 terminators. For example, a delay of about 1 *usec*, will ensure the time separation of the re-transmitted signal, from the original received signal, and hence the ability to mitigate the re-transmitted signal by the example "Channel Filtering" technique, which is discussed later. The said delay can be introduced in the Signal Conditioning unit 1048, provided that there is a digital data buffer of sufficient size available. The said Channel Filtering operation can also be performed by the Signal Conditioning unit 1048 (or SC unit 2046), or can be performed by a separate ASIC or FPGA, connected to the AD/C unit 1046, and the Signal Conditioning unit 1048. Alternatively, with minor modifications, the "channel filtering" (ASIC or the FPGA) unit can be placed in the User unit 2002, connected to the AD/C unit 2044 and Signal Conditioning unit 2046. The channel-sounding signal can be used for channel estimation purposes, so that the amplitude and the phase of the overall channel response (including

the return path) can be estimated during the channel-sounding mode (after the convergence of the complex-weight unit 1072 weights, W_0 and W_1), for the setting of the Channel Filter taps. The introduction of Channel Filter in the signal path also has an impact on the operation of the antenna diversity scheme. As the complex channel estimation has to be performed, the antenna switching operations are required to be synchronized, so that, out of all possible switched antenna combinations, only two possibilities exist. Since the antenna switching (selection) is under the control of micro-controller unit 1060 in the Network unit 1002, and micro-controller 2054 in the User unit 2002, channel estimation can be performed for two propagation paths, and two sets of Channel Filter coefficients can be determined for filtering operation. Therefore, it is possible to select (or switch to) the relevant filter coefficients, synchronized and in harmony with the antenna selection operation. It has to be noted that, the Channel Filtering mechanism is not used to totally mitigate the returned signal; rather it is used to suppress it sufficiently, so that some system gain is possible for the signal boosting operation. The introduction of the said "deliberate delay" may also be used in conjunction with any other known signal-processing algorithm, to reduce the coupling between the two Network 1002 and User 2002 units. The above discussion is also relevant to the forward-link of the Network unit 1002 and the User unit 2002, and therefore the above "delay" and "Channel Filtering", with the aid of the forward-link calibration signal (shown in figure 2000) has to be performed in the forward-link of the User unit 2002.

Other techniques, such as the use of vertical polarization for antenna units 1004 and 1006, and horizontal polarization for antennas 2034 and 2036 can further improve the system performance. It is also possible to improve system performance by the use of directional antennas, as in conventional booster and repeater systems.

The control-flow description given for figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c) and 910, requires some modification for the inclusion of the "Channel filtering" channel estimation in the digital implementation of the Network unit 1002 and User unit 2002.

As already mentioned, the above description is only an example of how the system may be implemented, and it is appreciated that it is not the only possible method and solution. There are several points that need to be noted.

1- It is possible for the Network unit 1002 to control several User units, such as the User unit 2002. In such setups, the example control flows, shown in figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c) and 910 need some modifications such that the Network Unit 1002 can initialize each User unit independently at first, and together in a final step. It is also desirable, in a scenario with several User units such as 2002, that the Network unit 1002 weights are converged for the User unit that has the minimum Up-link System Path Loss, PL_{ul}, with the Network unit 1002. Therefore each User unit (2002) in a booster network may require a unique code phase.

2- Another modification that is required for multi User unit (several User units 2002) operation is that the final weights convergence of all the units in a booster network (Network and User units) should be carried out with all User units, under the control of the Network unit 1002, active in the channel-sounding operation, such that combined signal power levels do not exceed the safe limit. If combined signal from the User Units exceeds the acceptable level for either of the reverse or forward system links, the appropriate weights have to be modified, in a iterative step increments, to such level that the maximum allowed system link gains, of the forward and the reverse links are met.

3- Although the signal path in both the Network unit 1002 and the User unit 2002, in the forward link direction, always needs to be active, in order to boost the beacon (BCCH in GSM) transmissions of the base stations, the reverse-link signal path of the Network unit 1002 and the User unit 2002 need not to be active, unless a substantial signal level is detected, based on the presence of uplink signal (i.e. "gated"). Care has to be taken that the reverse-link "gated" operation mentioned above, does not interfere with the channel-sounding signal path and mechanism involving the units 1058 and 1016. Therefore, the "gated" operation has to become continuous operation (as discussed in the main description) during the channel-sounding process, with channel sounding carried out on regular bases.

4- With certain modifications in the hardware and the control software, it is possible to merge the Network unit 1002 and the User unit 2002 into a single unit, connected "back-to-back". The design and operation of the back-to-back option is shown in figure 2250 and discussed later.

5- It is also possible to transmit the unique Network unit 1002 identity code, and optionally device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded (protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the Network unit 1002. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the Network unit 1002. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station requires base station receiver modifications, but does not affect the normal operation of the cellular link.

6- It is also possible and desirable to include in the system design, Closed-loop power control mechanism, between the Network unit 1002 and User unit 2002 for the unlicensed band (U-NII) operation, both in forward and reverse links of the system. Such closed-loop power control mechanism can be based on very low-

rate (e.g. 10 Hz) differential or absolute power control commands (based on received signal power), to increase or reduce the U-NII band transmission powers, such that only sufficient power is transmitted from the antennas 1036, 1038 on the Network unit 1002 side, and antennas 2004 and 2006 on the User unit 2002 side, for correct operation. This may require variable gain amplifiers for the transmission of the U-NII band, both in the Network unit 1002 and the User unit 2002. The closed-loop power control messages can be exchanged between the Network unit 1002 and the User unit 2002, via the control link units 1062 and 2056 in forward and reverse-links.

7- On the Network unit 1002 side, once the complex-weight unit 1072 weights, W_0 and W_1, are converged, it is possible to superimpose spatial dither on the antenna radiation pattern, such that the multipath standing waves patterns are sufficiently disturbed to provide some diversity gain on the Up-link. It is also possible to converge a second set of weights that keep the spatial position of the "nulls", while changing the radiation pattern sufficiently, to provide antenna radiation pattern diversity. Such weights can be converged by first performing direction finding (such as DFT) on the original weights to identify the 'Null" position, and forming new weights using algorithms such as Minimum-Variance Linear-Constraint Beam-forming algorithms (MVLCBF), with the constraint being the position of the spatial "Null". Repeated switching between the two sets of weights will provide antenna pattern diversity gain on the up-link. The same is applicable to the User unit 2002 for Down-link path.

8- In the above example of the Network unit 1002 and the User unit 2002, only two sets of complex weights W_0 and W_1, are used in the complex-weight units 1072 and 2072, as two diversity antennas are readily available at both units. However, it is appreciated that both in the Network unit 1002 and in the User unit 2002, more than two antennas and hence more than two weights can be used, based on the above description with minor modifications.

9- Although, the complex-weight units 1072 (in the Network unit 1002) and 2072 (in the Network unit 2002) are for transmitter beam-forming, it is possible to use similar complex weight units at the input to the receivers of the forward-link of the Network unit 1002 (in place of the RF switch 1008) and the reverse-link of the User unit 2002 (in place of the RF switch 2032) so that receiver beam-forming can also be performed. The receiver weight convergence can be based on similar procedure as the transmitter one, with only minor changes.

10- It is possible to converge the weights (W_0 and W_1) of the complex-weight units 1072 (in the Network unit 1002) and 2072 (in the Network unit 2002), with the reverse-link of the Network unit 1002 not operational (i.e. not receiving and transmitting the up-link cellular band signals within the SC unit 1048), and forward-link of the User unit 2002 not operational (i.e. not receiving and transmitting the down-link cellular band signals within the SC unit 2020), such that cellular signals are not repeated (transmitted). This will allow the

convergence of the weights (W_0 and W_1) of the complex-weight units 1072 (in the Network unit 1002) and 2072 (in the Network unit 2002) first, before the start of the booster normal operation.

The above discussion is applicable to all the different digital implementations of all the various boosters discussed in this invention.

2.3 Back-to-Back Booster

In a Back-to-Back arrangement, there is no need for the transmission and reception in U-NII band and the control link that exists between the Network unit 602 and the User unit 702. Figure 2250 depicts an analogue implementation example of such an arrangement, where the booster is placed where good signal coverage exists, indoor or outdoors. The back-to-back unit 2252 consists of antennas 2254, 2256, 2282 and 2280, all operating in the cellular spectrum of interest. Antennas 2254 and 2256 are connected to the duplex filters 2260 and 2259 respectively. The RF switch 2258 is also connected to the duplex filters 2260 and 2259, to provide antenna switched diversity operation for receive operation as discussed for Network unit 602 (and User unit 702). In the forward-link, the RF switch unit 2258 is connected to the LNA 2288 in the Forward-link unit 2264, via the directional coupler 2261. The directional coupler unit 2261 is also connected to calibration signal receiver unit 2263. The LNA 2288 is connected to the filter unit 2286. The bandpass filter unit 2286 can be designed to pass all or a desired part of the interested cellular spectrum, or can be a bank of overlapping bandpass filters, covering the full spectrum of the interested cellular system, with a RF switch, such that the desired band and bandwidth can be selected manually or automatically. Filter unit 2286 is connected to the power amplifier 2284. The power amplifier unit 2284 is connected to the directional coupler 2267. The directional coupler 2267 is connected to power splitter unit (hybrid combiner) 2299, and the calibration signal generator and transmitter unit 2265. Power splitter unit (hybrid combiner) 2299 is connected to the complex-weight unit 2269. The complex-weight unit 2269 is connected to the duplex filters 2276 and 2277 and the micro-controller 2270. The duplex filters 2276 and 2277 are connected to antennas 2280 and 2282 and connected to the RF switch 2278. On the reverse-link, the RF switch unit 2278 is connected to directional coupler unit 2274. The directional coupler unit 2274 is connected to calibration signal receiver 2272 and LNA 2290 in the Reverse-link unit 2266. The calibration signal receiver unit 2272 is capable of establishing the received signal strength and phase (complex channel impulse response that exists between the combined outputs of antennas 2254 and 2256, and the input to the calibration signal receiver 2272), either by correlation operation, similar to a RAKE receiver path searcher, or by matrix inversion operation on an appropriate block of sampled received signal, as discussed in the appendix A. The calibration signal receiver unit 2272 includes many sub-units, including a frequency converter, to return the calibration signal to base-band frequencies and other units such as A/D converters and base-band processors to perform the necessary base-band algorithms, which are not shown in the diagram. The LNA 2290 is connected to filter unit 2292, which is connected to power amplifier unit 2294. The bandpass filter 2292 can be designed to pass all or a desired part of the interested cellular spectrum, or can be a bank of overlapping bandpass filters, covering the full spectrum of the interested cellular system, with a RF switch, such that the desired band and bandwidth can be selected manually or automatically. The power amplifier 2294 is connected to directional coupler unit 2262. Directional coupler unit 2262 is connected to the calibration signal generator and transmitter unit 2268 and power splitter unit (hybrid combiner) 2296. Power splitter unit (hybrid combiner) 2296 is connected to the complex-weight unit 2298. The complex-weight unit 2298 is connected to the duplex filters 2260

and 2259 and the micro-controller 2270. The duplex filters 2260 and 2259 are connected to antennas 2254 and 2256 and connected to the RF switch 2258. The micro-controller 2270 is connected to calibration signal generator and transmitter units 2268 and 2265, the calibration signal receiver units 2272 and 2263, the Reverse-link unit 2266 and Forward-link unit 2264. A simple user interface unit 2271, which can be a keypad or simple dipswitch, is connected to micro-controller unit 2270.

Although many functional units of the Network unit 602 and the User unit 702 are not needed in the back-to-back unit 2252, the operation and the remaining units of the booster remain fundamentally the same as the ones described for the Network unit 602 and User unit 702. The operation and description of the calibration signal generator and transmitter units 2268 and 2265, and the calibration signal receiver units 2272 and 2263, in the reverse-link and forward-link are fundamentally similar to the ones described for the Network unit 602 and User unit 702. Since the antenna units 2254, 2256, 2282 and 2280 are placed close to each other, extra antenna isolation can be provided by highly directional antennas, with increased front-to-back radiation ratios.

It is also possible to transmit the unique unit 2252 identity code, and optionally device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded (protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the unit 2252. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the unit 2252. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station requires base station receiver modifications, but does not affect the normal operation of the cellular link.

Figure 2300 depicts a digital implementation example of Back-to-Back arrangement, where the booster is placed where good signal coverage exists, indoor or outdoors. The back-to-back unit 2302 consists of antennas 2304, 2306, 2328 and 2330, all operating in the cellular spectrum of interest. Antennas 2304 and 2306 are connected to the duplex filters 2310 and 2309 respectively. The RF switch 2308 is also connected to the duplex filters 2310 and 2309, to provide antenna switched diversity operation for receive operation as discussed for Network unit 1002 (and User unit 2002). In the forward-link, the RF switch unit 2308 is connected to the LNA 2312. The directional coupler unit 2311 is connected to output of the LNA 2312, and the calibration receiver unit 2305. The calibration receiver 2305 is also connected to micro-controller 2350. The directional coupler unit 2311 is also connected to the frequency converter unit 2313. Frequency converter 2313 is connected to Automatic Gain Control (AGC) unit 2314. The frequency converter 2313 converts the frequency band of the incoming signal from the cellular band to baseband, or "near baseband" frequency band. The frequency converter unit 2313

includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 2313 is set by micro-controller unit 2350. The AGC unit 2314 is connected to Analogue-to-Digital Converter (AD/C) unit 2316. The AGC 2314 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 2316. If included, care has to be taken in the design and operation of this unit (2314), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 2314. Also, care has to be taken, so that the gain contribution of the AGC unit 2314 is compensated for in the final Down-link System Link Gain, G_{dl} calculations, or alternatively the gain value of the AGC 2314 is compensated for in the SC unit 2318. If AGC unit 2314 is used in the booster unit 2300, and booster the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC unit 2314 bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If the AGC unit 2314 is not included, the AD/C unit 2316 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 2316 is connected to Signal Conditioning unit 2318. The Signal Conditioning unit 2318 performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, signal level estimation, AGC algorithm, and any other features that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link cellular or PCS or desired frequency spectrum. Depending on the system parameters such as the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 2318 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 2318 includes all the required interfaces and memory. The Signal Conditioning unit 2318 is connected to Digital-to-Analogue Converter (DA/C) unit 2320. The DA/C unit 2320 includes the required post filtering that is required after the digital to analogue conversion. The DA/C unit 2320 is connected to frequency converter unit 2321. Frequency converter unit 2321 up-converts the frequencies of the input signal to the original band of cellular frequencies. The frequency converter unit 2321 includes all the required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 2321 is set by micro-controller unit 2350. The frequency converter unit 2321 is connected to the power amplifier unit 2322, which is connected to the directional coupler unit 2325. The directional coupler unit 2325 is connected to the calibration signal generator and transmitter unit 2323 and the power splitter unit (hybrid combiner) 2358. Power splitter unit (hybrid combiner) 2358 is connected to the complex-weight unit 2360. The complex-weight unit 2360 is connected to the duplex filters 2324 and 2327 and the micro-controller 2350. The duplex filters 2324 and 2327 are connected to antennas 2328 and 2330 and connected to the RF switch 2326. The calibration signal generator and transmitter unit 2323 is also connected to the micro-controller 2350. On the reverse-link, the RF switch unit 2326 is connected to micro-controller 2350 and also connected to LNA unit 2332. The LNA unit 2332 is connected to the directional coupler unit 2334.

The directional coupler unit 2334 is connected to the frequency converter unit 2335. Frequency converter 2335 is connected to Automatic Gain Control (AGC) unit 2336. The frequency converter 2335 converts the frequency band of the incoming signal from the cellular band to baseband, or "near baseband" frequency band. The frequency converter unit 2335 includes all required filtering for the correct operation of the receiver chain. The operating frequency of the frequency converter unit 2335 is set by micro-controller unit 2350. The directional coupler unit 2334 is also connected to calibration signal receiver unit 2348. The frequency converter unit 2335 is connected to AGC unit 2336. The AGC unit 2336 is connected to Analogue-to-Digital Converter (AD/C) unit 2338. The AGC 2336 is optional, and its task is to place the received signal level substantially close to the middle of the dynamic range of the AD/C 2338. If included, care has to be taken in the design and operation of this unit (2336), so that in the presence of low signal power, noise within the operating bandwidth does not dominate the operation of the AGC unit 2336. Also, care has to be taken, so that the gain contribution of the AGC unit 2336 is compensated for in the final Up-link System Link Gain, G_{ul} calculations, or alternatively the gain value of the AGC 2336 is compensated for in the SC unit 2340. If AGC unit 2336 is used in booster unit 2300 and the unit is designed for CDMA cellular networks, care has to be taken in selecting the AGC unit 2336 bandwidth such that it is much smaller than the power control repetition rate of the CDMA system (e.g. less than 1.5kHz in WCDMA networks), so that the AGC operation does not interfere with the closed-loop power control mechanism. If the AGC unit 2336 is not included, the AD/C unit 2338 has to provide the required dynamic range, which can be as high as 192dB (32-bits). The AD/C unit 2338 is connected to Signal Conditioning unit 2340. The Signal Conditioning unit 2340 performs such tasks as channel select filtering for the desired operating frequency band, frequency conversion, signal level estimation, AGC algorithm, and any other features that require signal conditioning and processing. For example, the channel select filters that can be implemented as poly-phased filters can be set for a given operating bandwidth of 1.3, 5, 10 or 15 MHz, operating at any position within the forward-link cellular or PCS or desired frequency spectrum. Depending on the system parameters such as the required operational bandwidth and the load of the supported operations, such as filtering, the Signal Conditioning unit 2340 may be implemented by a variety of technologies such as FPGAs, ASICs and general purpose DSPs such as Texas Instruments TMS320C6416-7E3 processor. The Signal Conditioning unit 2340 includes all the required interfaces and memory. The Signal Conditioning unit 2340 is connected to Digital-to-Analogue Converter (DA/C) unit 2342. The DA/C unit 2342 includes the required post filtering that is required after the digital to analogue conversion. The DA/C unit 2342 is connected to the Frequency converter unit 2343, which up-converts the frequencies of the input signal to the desired portion of cellular or PCS band of frequencies. The frequency converter unit 2343 includes all required filtering for the correct operation of the transmitter chain. The operating frequency of the frequency converter unit 2343 is set by micro-controller unit 2350. The frequency converter unit 2343 is connected to the power amplifier unit 2344, which is connected to the directional coupler unit 2346. Directional coupler unit 2346 is connected to the calibration signal generator and transmitter unit 2352 and power splitter unit (hybrid combiner) 2354. Power splitter unit (hybrid combiner) 2354 is connected to the complex-weight unit 2356. The complex-weight unit 2356 is connected to the duplex filters 2309 and 2310 and the

micro-controller 2350. The duplex filters 2310 and 2309 are connected to antennas 2304 and 2306 and connected to the RF switch 2308. The micro-controller 2350 is connected to calibration signal generator and transmitter units 2352 and 2323, the calibration signal receiver units 2348 and 2305. A simple user interface unit 2351, which can be a keypad or simple dipswitch, is connected to micro-controller unit 2350. Units 2305, 2323, 2313, 2321, 2348, 2335, 2343, 2352 and 2350 are either connected to local oscillator unit 2356, or derive their clock or reference frequencies (via clock unit 2353) from the local oscillator 2356. The Signal Conditioning units 2318 and 2340 clock frequencies are provided by clock unit 2353.

Although many functional units of the Network 1002 and the User 2002 units are not needed in the back-to-back unit 2302, the operation and the function of most of the units of the booster 2302 remain fundamentally the same as the ones described for the Network unit 1002 and User unit 2002. In the digital implementation of booster unit 2302, the functional blocks for calibration signal generator and transmitter unit 2352, and the calibration receiver unit 2348 can be included in the Signal Conditioning unit 2340 for the uplink, and in the Signal Conditioning unit 2318 for the downlink operation. The operation and description of the calibration signal generator and transmitter units 2352 and 2323, and the calibration signal receiver units 2348 and 2305, in the reverse-link and forward-link are fundamentally similar to the one described for the Network unit 1002 and User unit 2002. Since the antenna units 2304, 2306, 2328 and 2330 are placed close to each other, antenna isolation can be provided by highly directional antennas, with increased front-to-back radiation ratios.

Considering only the reverse-link operation of the booster 2302, as an example, the signals received through antenna units 2328 and 2330 are re-transmitted through the antenna units 2304 and 2306, at a higher signal power. These re-transmitted signals can be received again through the antenna units 2330 and 2328 (and have been termed above as the "Up-link Returned-Signal"), causing a signal return path in the system that may cause instability in the operation of the booster. In the digital implementation of the booster unit 2302, it may be possible to reduce the magnitude of the returned signal (Up-link Returned-Signal) by various signal-processing techniques. The choice, design and effectiveness of a known or novel technique depend on the system parameters and the operating conditions, need to be studied well. Most known multipath mitigation algorithms can also be applied for return signal reduction, however, due to the extremely small propagation delays between the antenna units 2304, 2306 and the antenna units 2328, 2330, and the limited temporal resolution of the system, conventional mulipath mitigation algorithms may be practically hard and expensive to implement, at best, or ineffective and detrimental, at worst. Therefore, an example of a novel filtering technique is provided (see the "Novel Channel Filtering" section), where a "deliberate" delay in the re-transmission of the received signal is used, to separate the returned signal (Up-link Returned-Signal) from the original incident signal, at the output of the antenna units 2328 and 2330 terminators. A delay of about 1 *usec* will ensure the time separation of the re-transmitted signal from the original received signal, and hence the ability to mitigate the re-transmitted signal, by the example channel filtering technique. The said delay can be introduced in the Signal Conditioning unit 2340, provided that there is a digital data

buffer of sufficient size available. The said Channel Filtering operation can also be performed by the Signal Conditioning unit 2340, or can be performed by a separate ASIC or FPGA, connected to the AD/C unit 2338, and the Signal Conditioning unit 2340. The calibration signal can be used for channel estimation purposes (after the convergence of the complex-weight unit 2356 weights, W_0 and W_1), so that the amplitude and the phase of the overall channel response (including the return path) can be estimated, for the setting of the Channel Filter taps. The introduction of Channel Filter in the signal path also has an impact on the operation of the antenna diversity scheme. As the channel estimation has to be performed, the antenna switching operations are required to be synchronized, so that, out of possible four, only two possibilities exist. Since the antenna switching (selection) is under the control of micro-controller unit 2350, channel estimation can be performed for two propagation paths, and two sets of Channel Filter coefficients can be determined for filtering operation. Therefore, it is possible to select (or switch to) the relevant filter coefficients, synchronized and in harmony with the antenna selection operation. It has to be noted that the Channel Filtering mechanism is not used to totally mitigate the returned signal; rather it is used to suppress it sufficiently, so that some system gain is possible for the signal boosting operation. The introduction of the said "deliberate delay" may also be used in conjunction with any other known signal-processing algorithm to reduce the coupling between the two antenna sets 2304 and 2306 and 2330 and 2328. The above discussion is also relevant to the forward-link of the booster unit 2302, and therefore the above "delay" and "Channel Filtering" have to be performed in the forward-link as well.

Other techniques, such as the use of vertical polarization for antenna units 2304 and 2306, and horizontal polarization for antennas 2328 and 2330 can further improve the system performance. It is also possible to improve system performance by the use of directional antennas, as in conventional booster and repeater systems.

It is also possible to transmit the unique unit 2302 identity code, and optionally device location, to the cellular network. This information can be used to locate a user in an indoor environment. This can be accomplished by generating a heavily coded (protected), low bit rate data, containing a long known preamble, the unique identity code and optionally the longitude and the latitude of the unit 2302. This information can then be pulse-shaped for low spectral leakage and superimposed on the reverse-link signal of a given channel by an appropriate modulation scheme, within the unit 2302. The choice of the modulation scheme depends on the operating cellular system. For example, for GSM, which enjoys a constant envelope modulation such as GMSK, amplitude modulation (with low modulation index) can be used for this purpose. For CDMA systems, with fast reverse-link power control, DBPSK can be used as the modulation scheme. The extraction of the above mentioned information from the received channel signal at base station requires base station receiver modifications, but does not affect the normal operation of the cellular link.

An example of the system operational flow diagrams for booster unit shown in figure 2300 (or 2250) is shown in the figure 2400. The example does not include all the possible

functionalities for the complete operation of the booster unit 2300 (or 2250). The example is used to show the minimum control flow that is required for the most basic operation of the booster unit 2302 (or 2252). On "power-up" or "reset" or a "Stop" instruction, the booster unit 2302 (or 2252) sets the complex-weight units 2360 and 2356 weights, W_0 and W_1, to "Initial" value by default. The "Initial" values (of the weights) are those that allow minimum power radiation from the two connected antennas, with no phase differential between the two radiated fields, i.e. broadside radiation. On "power-up" or "reset" instruction of the booster unit 2302 (or 2252), the micro-controller unit 2350 will start the control-flow (step 2402) in figure 2400(a). Micro-controller 2350 instructs the reverse-link calibration receiver 2348 to scan for all possible code offsets (step 2404). If a substantial signal power transmitted by other units, operating within the same geographical area, is detected by the receiver unit 2348 (step 2406), the received signal powers are stored (step 2408). If no substantial signal is detected (step 2410), the micro-controller 2350 instructs the forward-link calibration receiver 2305 to scan for all possible code offsets (step 2410). If a substantial signal power transmitted by other units, operating within the same geographical area, is detected by the receiver unit 2305 (step 2416), the received signal powers are stored (step 2414). After the test for all possible code offsets is finished for the forward and reverse links of the system, and if other units signal power is detected (step 2417), the received signals for each offset are tested and the largest signal power is selected (step 2412). If this selected signal power is above a safe threshold (step 2418), the unit 2302 displays an error message (step 2419) and stops operation (step 2422). If the selected signal power is below the safe threshold, the unit proceeds to step 2420. If no substantial signal is detected or the detected signals are below the safe threshold (step 2416), the micro-controller 2350 selects an unused code offset (step 2420) for both forward and reverse channel-sounding transmissions. Micro-controller 2350 sets the booster unit 2302 (or 2252) in "channel-sounding" mode (step 2424). In "channel-sounding" mode the diversity switches 2308 and 2326 are kept in the current position (i.e. not switching). Micro-controller 2350 sets the complex-weight units 2356 and 2360 weights, W_0 and W_1, to the "Initial" value (step 2426). Micro-controller 2350 instructs calibration signal generator and transmitter units 2352 and 2323 to commence transmission with the specified "own code" phase (step 2428) continuously. The micro-controller 2350 will also instruct the up-link calibration signal receiver unit 2348 to try to receive the channel-sounding signal for the above mentioned code offset, used by the transmitter unit 2352 (step 2430). If no substantial channel-sounding signal is detected with the specified set of weights of the complex-weight unit 2356 and Up-link System Link Gain, G_{ul}, is less than the specified maximum allowed system gain (2434), micro-controller 2350 will modify and issue new up-link weight values to complex-weight unit 2356, such that the transmit power of the channel-sounding signal from antenna units 2304 and 2306 is increased by a predetermined step size, dG, while keeping the relative phases of the weights (W_0 and W_1) the same (step 2436). Steps 2430, 2432, 2434 and 2436 are repeated until a substantial channel-sounding signal is detected for uplink path, or the maximum allowed up-link system gain is reached. If maximum allowed up-link system gain is reached, the most recent weights are kept (frozen) as the most optimum weights for normal operation (step 2438). If maximum allowed system gain is not reached, and there is substantial channel-sounding signal at the output of the calibration signal receiver 2348, an adaptive convergence algorithm such as LMS is used

to further modify the weights (W_0 and W_1), such that the channel-sounding signal power is minimized (step 2442). The new weights are issued to the complex-weight unit 2356 for transmission of the channel-sounding signal (step 2444). If the up-link weights are sufficiently converged, the control-flow will proceed to next step, otherwise, steps 2430 to 2446 are repeated. After the successful convergence of the up-link weights (W_0 and W_1), micro-controller 2350 will converge the down-link weights (steps 2448 to 2460) in much the same way as the up-link weights. After the successful convergence of both up-link and down-link weights, micro-controller 2350 exits the channel-sounding mode (step 2462). Micro-controller 2350 instructs the calibration signal receivers 2348 and 2305 to continue to receive the channel-sounding signal transmitted by the calibration signal transmitter units 2352 and 2323 (step 2464). If the safe average channel-sounding signal power level is exceeded for a substantial amount of time (step 2468), for up-link or down-link path, the micro-controller 2350 will set both up-link and down-link weights to "Initial" value (step 2470) and return to step 2402 (step 2474). If the average channel-sounding signal power level is within the expected range, the calibration signal receiver units 2348 and 2305 are instructed to receive and detect channel-sounding signals with all other possible code offsets (step 2469). If no channel-sounding signal with substantial average signal power level is detected in the up-link or down-link, the micro-controller 2350 will return to step 2464 (step 2472). The channel-sounding operation can be initiated on regular bases to ensure correct operation, before detection of excess signal in either the up-link pr down-link of the booster 2302 (2252) paths.

2.4 Novel Channel Filtering Example

The example provided here can be applied to the booster system described here to combat the effect of mentioned feed-back loop and the above mentioned Up-link Returned-Signal that may exist in the reverse-link of the system and Down-link Returned-Signal that may exist in the forward-link of the system. The "Channel Filtering" technique, discussed here, for the forward and the reverse links is autonomous and can either be applied to both or just one of the forward or the reverse links of the system, and can be implemented in the Network unit 1002 or the User unit 2002, or both. To explain the working of the Novel Channel filtering, a simplified block diagram of the booster, with this feature in isolation, is shown in figure 2450, and only the reverse-link operation is discussed for the Network unit 1002 and User unit 2002 (the Channel Filtering discussed here is applicable to all digital implementations). In this representation, no antenna diversity is assumed for either the Network unit 2452 (which is substantially similar to 1002 in figure 1000) or the User unit 2454 (which is substantially similar to 2002 in figure 2000). The processing and propagation delays within the booster system can be categorized as the following:

τ_{Us} = the User unit 2454 processing delay (relatively negligible).
τ_{P1} = the unlicensed band propagation delay.
τ_{Nrx} = the Network unit 2452 receiver processing delay (relatively negligible).
τ_{Ntx} = the Network unit 2452 transmitter processing delay (relatively negligible).
τ_d = the "deliberate" delay introduced in the transmission path of the Network unit 2452.
τ_{P2} = the licensed band propagation delay of the Up-link Returned-Signal.

The overall impulse response of the booster unit 2451 is shown in 2464. The original incident pulse, entering from antenna 2462 (A1), arrives at the input to the Network unit 2452 receiver after a delay of τ_f, (the pulse is marked as 2468), where:

$$\tau_f = \tau_{Us} + \tau_{P1} \simeq \tau_{P1}$$

This pulse is amplified and transmitted 2470, after the "deliberate" time delay τ_d, from antenna 2456 (marked A4 in figure 2450). The transmitted signal re-enters the antenna 2462 (A1) after the propagation delay τ_{P2} , and arrives at the input to the Network unit 2452 receiver after a delay of τ_f (marked as 2472). So the overall delay for the Up-link Returned-Signal at the input to the Network unit 2452 receiver can be stated as τ_t and is substantially equal to:

$$\tau_t = \tau_{Nrx} + \tau_d + \tau_{Ntx} + \tau_{P2} + \tau_f \simeq \tau_d + \tau_{P1} + \tau_{P2}$$

The returned pulse 2472 is delayed by the propagation path delays τ_{P1} and τ_{P2}, which can be very small in the booster's operating environment. The "deliberate" delay is introduced to sufficiently separate the Up-link Returned-Signal from the original incident pulse, such that filter coefficients can be estimated easily, and filtering can be performed

more effectively. Note that the introduction of another "deliberate" delay in the transmit path of the User unit 2454 will ensure separation of the boosted transmitted pulse and the Up-link Returned-Signal. This may be desirable, to reduce the effect of the multipath experienced by the boosted transmitted pulse, on the operation of the Channel filtering.

In the example here, the "Channel Filtering" unit 2512 (in figure 2500) is placed only on the reverse-link of the Network unit 1002. The channel filtering process requires an estimate of the complex propagation channel impulse response, which includes the amplitude and phase for all time delays, up to the maximum expected multipath delay. The complex channel impulse response, $C(t,\tau)$, can be provided by the calibration signal receiver unit 1016 shown in figure 1000, as this information is readily available at the output of this unit, for the reverse-link path of the system. Note that based on the described design of the calibration signal mechanism shown in figure 1000 (also figure 2300), the channel impulse response, provided by the calibration signal receiver unit 1016, will not include the delay contributions of the "deliberate" delay (τ_d), and the $\tau_{Nrx} + \tau_{Ntx}$ components. While $\tau_{Nrx} + \tau_{Ntx}$ is sufficiently small to ignore, the "deliberate" delay (τ_d) has to be added in the overall impulse response, in the Network unit 1002, for the estimation of the Channel Filter coefficients. Equally, if Channel Filtering operation is also required for the forward-link, a separate complex channel impulse response is required for this link of the system, which effectively means that similar calibration mechanism, as the reverse-link, is required on the forward-link of the system. An example of the estimated power of the channel impulse response, $C(t,\tau)$, 2510, at the output of the calibration signal receiver 1016 is shown in figure 2500. The impulse response 2510 is for a maximum delay of 1 *usec*, assuming a calibration signal PN code chipping rate of 5 *Mchips/sec* and 2 samples per chip. In figure 2500, $C(t,\tau)$ 2510 has three substantial distinguishable propagation paths at delays of 0.2 (P1), 0.4 (P2) and 1.0 (P3) *usec* respectively. The maximum expected time delay corresponds to a signal path of about 300 meters, which is reasonable for the booster range and operational environment. The 1.0 *usec* maximum time delay, together with a "deliberate delay of 1 *usec* ($\tau_d = 1$ *usec*), requires a 21-tap complex FIR filter, with half-chip tap spacing, for Channel Filtering operation. Figure 2500 shows the Channel Filter unit 2512. The Channel Filter unit 2512 has a 21-tap FIR filter 2506, with tap delay of $D = 0.1$ *usec* spacing, and with the variable complex coefficients set to the values shown in table 2508. The FIR filter 2506 output is connected to one of the inputs of the adder unit 2504, and the input of the FIR filter unit 2506 is connected to the output of the adder unit 2504. The other input of the adder unit 2504 is connected to the AD/C 2502. In this example, this AD/C is the unit 1046 in figure 1000. The FIR filter 2506 will produce a replica of the received signal, at the desired time delay with the respective complex coefficient specifying the magnitudes and the phases of the received Up-link Returned-Signal, to "wipe off" the incoming first (P1), second (P2) and third (P3) return signal components. The FIR filter 2506 can either be implemented by a FPGA, ASIC or by the Signal Conditioning unit 1048 in figure 1000. The processes of channel estimation, $C(t,\tau)$, and hence up-dating the FIR filter 2506 filter coefficients, have to be performed continuously, with an update rate that depends on the channel coherence time. For this example, a value of 100 *msec* can be assumed, as the indoor channels exhibit large coherence time. Alternatively, it is possible to use an adaptive algorithm such as Normalized LMS (NLMS), or RLS, converging on

the received calibration signal at the Network unit 1002, to estimate the filter coefficients, on an on-going basis.

2.5 Wire Connected Booster

Figure 3000 shows an example of analogue implementation of the Network unit 600 using a transmission cable as the physical medium for communication with the User unit 4000 (702 in figure 700). The Network unit 602 shown in figure 600 is modified to the unit 3005 shown in figure 3000 to transmit to, and receive signals from, the User unit 4005 (figure 4000), which is a modified version of the User unit 702 shown in figure 700, over a cable capable of supporting the operating bandwidth and the frequencies of the Network unit 3005 and User unit 4005 signals. The cable interface unit 3020 consists of a line interface unit 3160 which is connected to the transmission/reception cable 3170 and two hybrid combiners 3140 on the forward-link, and 3150 on the reverse link of the Network sub unit 3010. The line interface unit 3160 will provide the means for the load matching for connection to a transmission line 3170, and other required components such as the amplifiers, modulation and frequency converters (modem functionalities), for reliable transmission over the transmission line 3170. The design of the line interface unit 3160 is dependent on the transmission line 3170 characteristics, and is well known in the art. For example, even the in-building power lines or telephone lines can be used as the transmission line 3170 (as in homePNA and HomeNetworking) for this purpose, where the line interface unit 3160 is designed for such operation. The hybrid combiner (or directional coupler) 3140 is used to combine the control link 3110 signal with the forward-link signal. Alternatively, the outputs of the directional coupler unit 3040 and the control link unit 3110 can directly be connected to line interface unit 3160, where they are modulated on adjacent carriers for simultaneous transmission to the User unit 4005. The hybrid combiner (or directional coupler) 3150 is used to extract sufficient signal for reception and detection of control link 3110 received signal. Alternatively, the inputs to the directional coupler unit 3130 and the control link unit 3110 can directly be connected to line interface unit 3160, if the control and data signals are modulated on adjacent carriers for simultaneous transmission from the User unit 4005. It is also possible to use hybrid combiners instead of the directional couplers 3040, 3130 and 3085. It is also possible, and is more desirable, to place the Reverse-link Network unit 3060 receiver internal LNA amplifier, before the directional coupler 3130 (or the hybrid combiner replacement), in diagram 3000.

The operation of the units 3015, 3030, 3050, 3120, 3110, 3060, 3100, 3105, 3070, 3074, 3078, 3080, 3085, 3040, 3130, 3072, 3092, 3094 and 3090 in figure 3000 is similar, in operation and description, to 640, 624, 604, 620, 628, 606, 626, 627, 614, 610, 608, 612, 618, 630, 616, 613, 646, 648 and 622 respectively, as discussed for figure 600. In the modified Network unit 3005, the directional coupler 3040 (630 in figure 600) is connected to hybrid combiner 3140, and the directional coupler 3130 (616 in figure 600) is connected to hybrid combiner 3150.

Figure 4000 shows an example of analogue implementation of the User unit 702 (figure 700) using a transmission cable as the physical medium for communication with the Network unit 3005 (602 in figure 600). The User unit 702 shown in figure 700 is

modified to the unit 4005 shown in figure 4000 to transmit to, and receive signals from, the Network unit 3005, which is a modified version of the Network unit 602 shown in figure 600, over a cable capable of supporting the operating bandwidth and the frequencies of the Network 3005 and User 4005 units signals. The cable interface unit 4020 consists of a line interface unit 4150 which is connected to the transmission/reception cable 4160 and two hybrid combiners 4130 on the forward-link and 4140 on the reverse link of the User sub unit 4010. The line interface unit 4150 will provide the means for the load matching for connection to a transmission line 4160, and other required components such as the amplifiers, modulation and frequency converters (modem functionalities), for reliable transmission over the transmission line 4160. The design of the line interface unit 4150 is dependent on the transmission line 4160 characteristics, and is well known in the art. For example, even the in-building power lines or telephone lines can be used as the transmission line 4160 (as in homePNA and HomeNetworking) for this purpose, where the line interface unit 4150 is designed for such operation. The hybrid combiner (or mixer or directional coupler) 4140 is used to combine the control link 4120 signal with the reverse-link signal. The hybrid combiner (or duplexer) 4130 is used to extract sufficient signal for reception and detection of control link 4120 received signal. It is also possible to use hybrid combiners instead of the directional coupler 4110. It is also possible, and is more desirable, to place the Forward-link User unit 4080 internal LNA amplifier, before the directional coupler 4110 (or the hybrid combiner replacement), in diagram 4000.

The operation of the units 4015, 4030, 4040, 4050, 4070, 4075, 4080, 4090, 4100, 4110, 4060, 4062, 4152, 4154, 4128, 4126, 4124, 4122 and 4120 in figure 4000 is similar, in operation and description, to 722, 734, 736, 732, 728, 721, 724, 726, 716, 718, 754, 756, 745, 748, 746, 744, 742, 740 and 720 respectively, as discussed for figure 700. In the modified User unit 4005, the directional coupler 4110 (718 in figure 700) is connected to hybrid combiner 4130, and the Reverse-link User unit 4090 (726 in figure 700) is connected to hybrid combiner 4140.

Apart from the mentioned differences, the operation of Network unit 3010 is similar to the operation of the Network unit 602 and the operation of User unit 4010 is similar to the operation of the User unit 702.

The control-flow description given for figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c), and 910 can also be used for the implementation of the Network unit 3005 and User unit 4005, which is discussed above in figures 3000 and 4000.

Figure 5000 shows an example of digital implementation of the Network unit 5005 (1002 in figure 1000), using a transmission cable as the physical medium for communication with the User unit 6005 (2002 in figure 2000). The Network unit 1002 shown in figure 1000 is modified to the unit 5005 shown in figure 5000 to transmit to, and receive signals from, the User unit 6005 (in figure 6000), which is the modified version of the User unit 2002 shown in figure 2000, over a cable capable of supporting the operating bandwidth and the frequencies of the Network 5005 and User 6005 units signals. The modified cable

interface unit 5020 consists of a line interface unit 5220, which is connected to the transmission/reception cable 5210 and the Line Modem unit 5250.

The line interface unit 5220 and the Line Modem unit 5250 will provide the means for the load matching for connection to transmission line 5210, and other required components such as the amplifiers, modulation and frequency converters, for reliable transmission over the transmission line 5210. The design of the line interface unit 5220 is dependent on the transmission line 5210 characteristics, and is well known in the art. For example, even the in-building power lines or telephone lines can be used as the transmission line 5210 (as in homePNA) for this purpose, where the line interface unit 5220 is designed for such operation. The line modem unit 5250 will provide the required modulation and demodulation AD/C, DA/C and all other modem functionalities for transmission of the signal generated by the unit 5010 and reception of signal generated by unit 6010. Also, the design of the modem unit 5250 is well known in the art, and as example technologies, homePNA and HomeNetworking can be mentioned. The line modem unit 5250 is connected to data muliplexer unit 5260 and data demultiplexer unit 5270. The line modem unit 5250 can be implemented in either analogue or digital technology (or a mix). In this example it is assumed that the line modem unit 5250 is implemented in digital domain.

Data multiplexer unit 5260 is also connected to Signal Conditioning unit 5110 and the control link unit 5145, and is used to multiplex control samples generated by control link unit 5145 and the signal samples generated by the Signal Conditioning unit 5110. The multiplexer unit 5260 can be integrated within the Signal Conditioning unit 5110. Alternatively, the output of the Signal Conditioning unit 5110 and control link unit 5145 can be separately connected to the line modem unit 5250, where they are modulated on adjacent carriers for simultaneous transmission to the User unit 6005.

Data Demultiplexer unit 5270 is also connected to Signal Conditioning unit 5130 and the control link unit 5145, and is used to demultiplex received control samples and the signal samples generated by the User unit 6005. The demultiplexer unit 5270 can be integrated within the Signal Conditioning unit 5130. Alternatively, the inputs to the Signal Conditioning unit 5130 and control link unit 5145 can be separately connected to the line modem unit 5250, if the control and data signals are modulated on adjacent carriers for simultaneous transmission by the User unit 6005.

In Network unit 5005, the calibration signal receiver unit (1016 in figure 1000) is no longer implemented separately. As no analogue signal path is available in the reverse-link of the Network unit 5005, the calibration signal receiver unit (1016 in figure 1000) is integrated and performed in the Signal Conditioning unit 5130.

The operation of the units 5110, 5120, 5130, 5140, 5141, 5145, 5386, 5100, 5150, 5090, 5160, 5080, 5170, 5070, 5180, 5190, 5060, 5050, 5040, 5082, 5060, 5064 and 5030 in figure 3000 is similar, in operation and description, to 1022, 1024, 1048, 1060, 1061, 1062, 1070, 1020, 1050, 1018, 1052, 1014, 1054, 1012, 1056, 1058, 1010, 1008, 1004, 1007, 1010, 1072 and 1006 respectively, as discussed for figure 1000.

Figure 6000 shows an example of digital implementation of the User unit 6005 (2002 in figure 2000) using a transmission cable as the physical medium for communication with the Network unit 5005 (1002 in figure 1000). The User unit 2002 shown in figure 2000 is modified to the unit 6005, shown in figure 6000, to transmit to, and receive signals from, the Network unit 5005, which is a modified version of the Network unit 1002, shown in figure 1000, over a cable capable of supporting the operating bandwidth and the frequencies of the Network 5005 and User 6005 units signals. The modified cable interface unit 6020 consists of a line interface unit 6230 which is connected to the transmission/reception cable 6240 and the line modem unit 6220.

The line interface unit 6230 and the Line Modem unit 6220 will provide the means for the load matching for connection to transmission line 6240, and other required components such as the amplifiers, modulation and frequency converters, for reliable transmission over the transmission line 6240. The design of the line interface unit 6230 is dependent on the transmission line 6240 characteristics, and is well known in the art. For example, even the in-building power lines or telephone lines can be used as the transmission line 6240 (as in homePNA) for this purpose, where the line interface unit 6230 is designed for such operation. The line modem unit 6220 will provide the required modulation and demodulation, AD/C, DA/C and all other functionalities for transmission of the signal generated by the unit 6010 and reception of signal generated by unit 5005. Also, the design of the modem unit 6220 is well known in the art, and as example technologies, homePNA and HomeNetworking can be mentioned. The line modem unit 6220 is connected to data muliplexer unit 6200 and data demultiplexer unit 6210. The line modem unit 6220 can be implemented in either analogue or digital technology (or a mix). In this example it is assumed that the line modem unit 6220 is implemented in digital domain.

Data multiplexer unit 6210 is also connected to Signal Conditioning unit 6140 and the control link unit 6150, and is used to multiplex control samples generated by control link unit 6150 and the signal samples generated by the Signal Conditioning unit 6140. The multiplexer unit 6210 can be integrated within the Signal Conditioning unit 6140. Alternatively, the output of the Signal Conditioning unit 6140 and control link unit 6150 can be separately connected to the line modem unit 6220, where they are modulated on adjacent carriers for simultaneous transmission to the Network unit 5005.

Data Demultiplexer unit 6200 is also connected to Signal Conditioning unit 6100 and the control link unit 6150, and is used to demultiplex received control samples and the signal samples generated by the Netwok unit 5005. The demultiplexer unit 6200 can be integrated within the Signal Conditioning unit 6100. Alternatively, the inputs to the Signal Conditioning unit 6100 and control link unit 6150 can be separately connected to the line modem unit 6220, if the control and data signals are modulated on adjacent carriers for simultaneous transmission by the Network unit 5005.

The operation of the units 6150, 6100, 6110, 6140, 6155, 6151, 6120, 6130, 6090, 6160, 6170, 6080, 6180, 6070, 6190, 6060, 6050, 6030, 6062, 6064, 6066, 6068, 6072 and 6040 in figure 6000 is similar, in operation and description, to 2056, 2020, 2022, 2046, 2054, 2055, 2021, 2023, 2024, 2044, 2042, 2026, 2040, 2028, 2038, 2030, 2032, 2034, 2031, 2072, 2070, 2027, 2025 and 2036 respectively, as discussed for figure 2000.

The control-flow description given for figures 800(a), 800(b), 800(c), 820, 900(a), 900(b), 900(c), and 910 can also be used for the digital implementation of the Network unit 5005 and User unit 6005, which is discussed above in figures 5000 and 6000.

Apart from the mentioned differences, the operation of Network unit 5010 is similar to the operation of the Network unit 1002 and the operation of User unit 6010 is similar to the operation of the User unit 2002.

Appendix A: Channel Estimation by Matrix Inversion

Almost most digital communications systems use a type of channel estimation. Channel estimation is usually based on a known transmitted sequence, known as "preamble" or "midamble" or "training sequence" amongst other names. The known sequence is required for channel estimation as various algorithms use the priori knowledge, to estimate the propagation channel complex parameters and characteristics. There are fundamentally two basic signal processing domains for channel estimation: 1- Time domain approach, and 2- frequency domain approach. The time domain approach includes many algorithms, most notably the "correlation" based and "Matrix inversion" algorithms. While correlation based channel estimation is preferred by most, mainly due to its simplicity and low computation requirements, Matrix inversion channel estimation yields better performance, at a higher computation cost. The "matrix inversion" channel estimation algorithms are well known in the art. However, a brief description is provided here for completion.

Consider estimation of the complex impulse response coefficients of a propagation channel of length n, by a single transmitted sequence that is using a known PN code of length s samples, where $s > n$. Let the time invariant channel coefficients be represented by matrix H given as:

$$H^T = [h_1\, h_2\, \dots\, h_n]$$

And the transmitted PN sequence as M given by:

$$M^T = [m_1\, m_2\, \dots\, m_s]$$

Notice that all s samples of the code are not needed for the channel sounding operation. The convolution between the Channel coefficients and the transmitted sequence yields the received signal e_t given by:

$$
\begin{aligned}
e_1 &= m_n.h_1 + \dots + m_2.h_{n-1} + m_1.h_n \\
e_2 &= m_{n+1}.h_1 + \dots + m_3.h_{n-1} + m_2.h_n \\
&\cdot \\
&\cdot \\
&\cdot \\
e_k &= m_{k+n}.h_1 + \dots + m_{k+1}.h_{n-1} + m_k.h_n
\end{aligned}
$$

Where t is time samples, and k is the maximum required estimation length and assuming $s > k+n$. The above set of equations, representing e_t, can be shown in matrix notation as the following:

$$E = V.H$$

Where the received complex samples, E, can be represented as:

$$E^T = [e_1 e_2 \dots e_k]$$

And

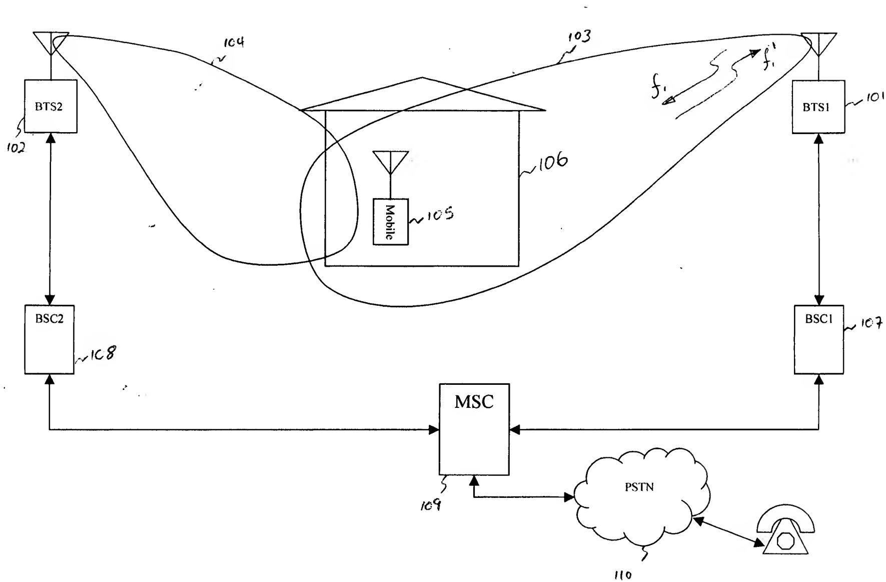
$$V = \begin{bmatrix} m_n & m_{n-1} & \cdots m_1 \\ m_{n+1} & m_n & \cdots m_2 \\ . & & \\ . & & \\ m_{k+n} & m_{k+n-1} & \cdots m_k \end{bmatrix}$$

The complex channel impulse response can be calculated by matrix inversion of V matrix as shown below:

$$I.H = V^1.E$$

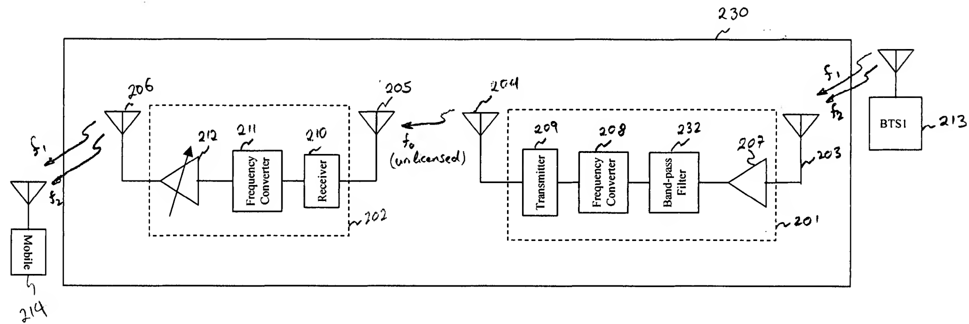
Where I is an Identity matrix with dimensions of $n \times n$. If $k = n$, unique values of the channel impulse response can be calculated using the above matrix inversion approach. V matrix can be pre-calculated and stored in memory, so that there is no need for high computation complexity.

100



104
103
f_1
f_1'
BTS2
BTS1
101
102
106
Mobile
105
BSC2
BSC1
107
108
MSC
109
PSTN
110

200


230
206
205
204
212
211
210
209
208
232
207
203
202
201
Frequency Converter
Receiver
Transmitter
Frequency Converter
Band-pass Filter
f_0 (unlicensed)
f_1
f_2
f_1
f_2
Mobile
214
BTS1
213

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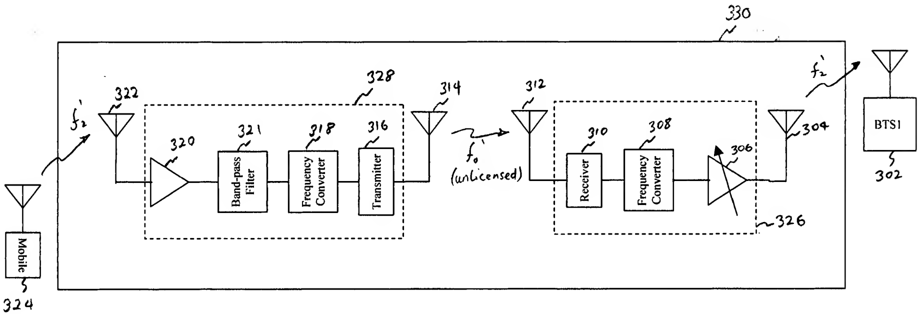
300



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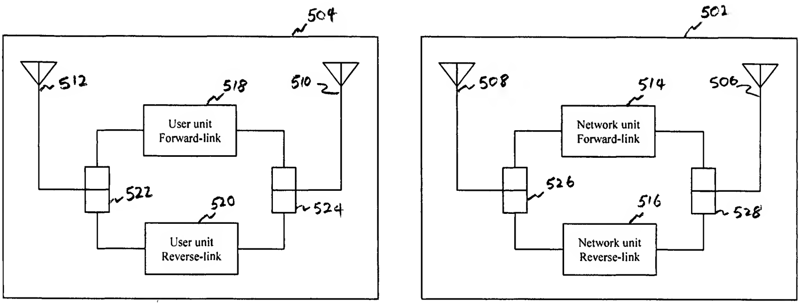
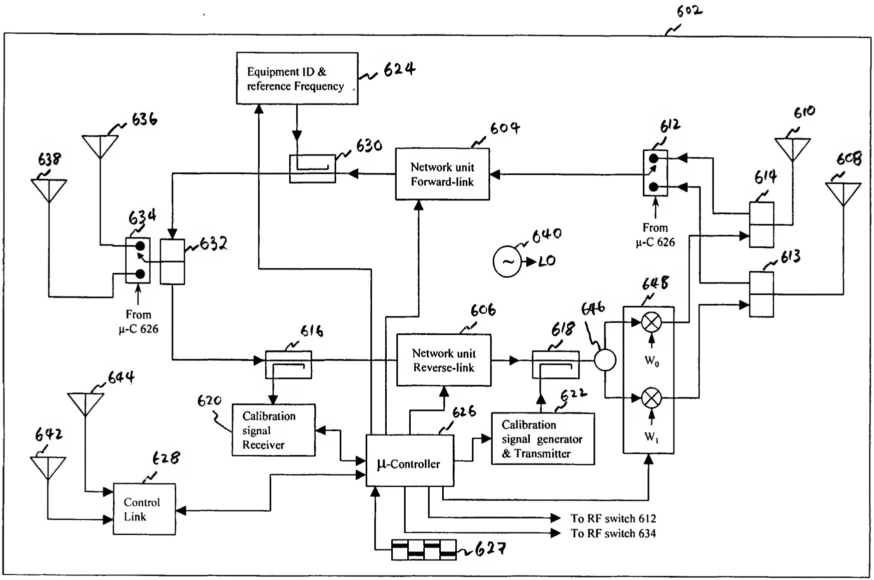
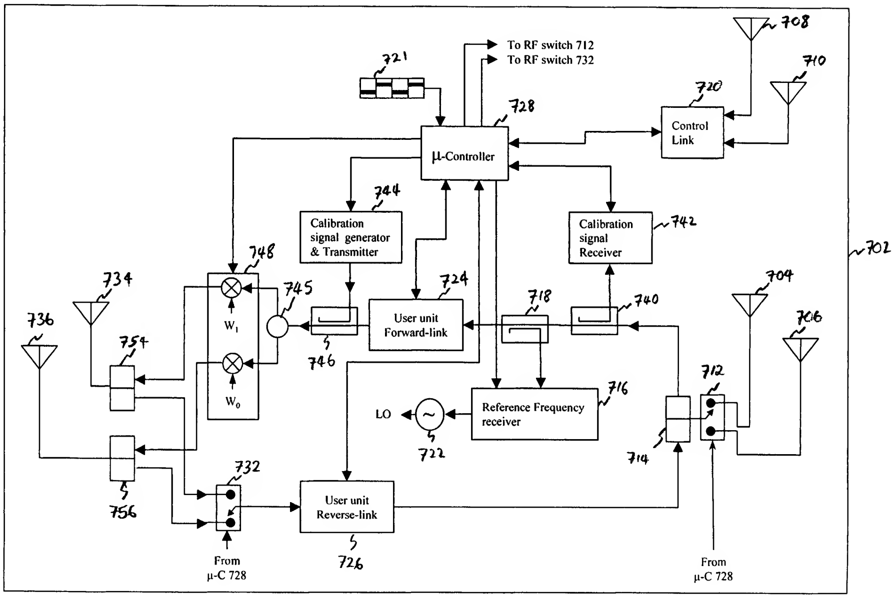
500

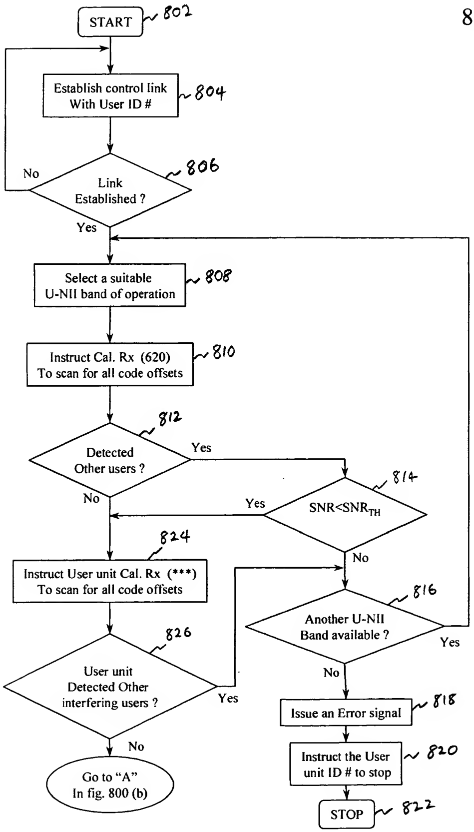

504
512
518
510
User unit
Forward-link
522
520
524
User unit
Reverse-link
502
508
514
506
Network unit
Forward-link
526
516
528
Network unit
Reverse-link

600

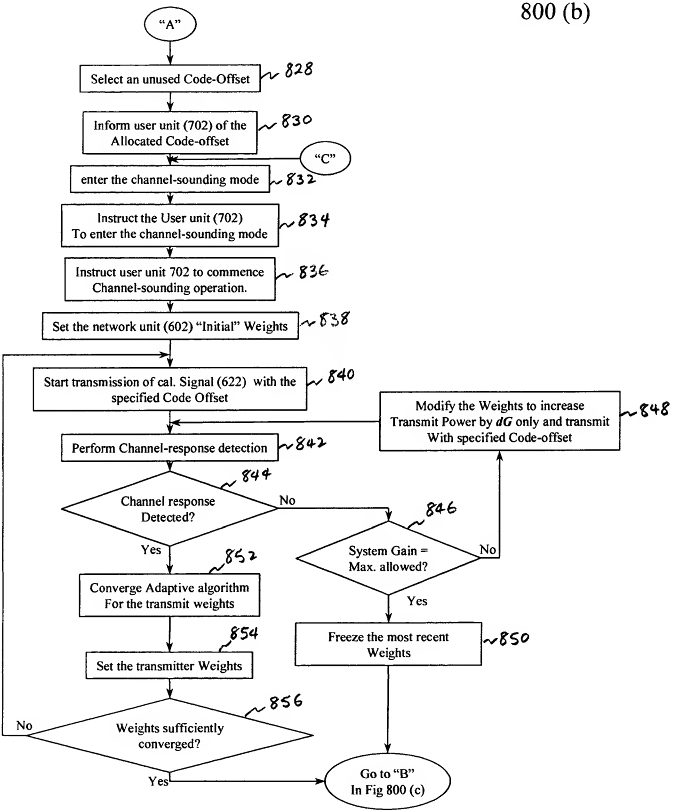

602
Equipment ID & reference Frequency
624
636
638
630
604
Network unit Forward-link
612
610
608
614
634
632
From µ-C 626
640
LO
613
From µ-C 626
648
606
646
616
618
Network unit Reverse-link
W0
644
620
622
626
Calibration signal Receiver
Calibration signal generator & Transmitter
W1
642
628
µ-Controller
Control Link
To RF switch 612
To RF switch 634
627


708
710
720
Control Link
721
To RF switch 712
To RF switch 732
728
μ-Controller
744
Calibration signal generator & Transmitter
742
Calibration signal Receiver
702
748
W1
W0
745
746
724
User unit Forward-link
718
740
704
706
734
736
754
756
732
From μ-C 728
User unit Reverse-link
726
LO
722
716
Reference Frequency receiver
712
714
From μ-C 728

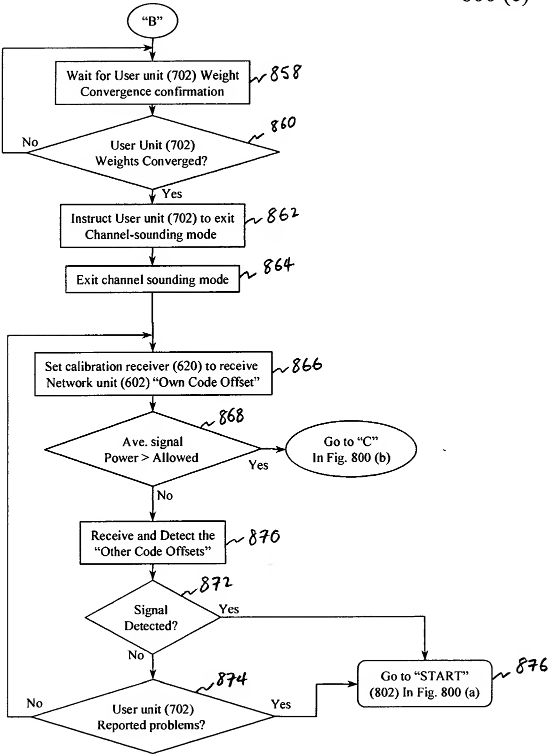
800 (a)


START
802
Establish control link
With User ID #
804
Link
Established ?
806
No
Yes
Select a suitable
U-NII band of operation
808
Instruct Cal. Rx (620)
To scan for all code offsets
810
Detected
Other users ?
812
Yes
No
SNR<SNR$_{TH}$
814
Yes
No
Instruct User unit Cal. Rx (***)
To scan for all code offsets
824
Another U-NII
Band available ?
816
Yes
No
User unit
Detected Other
interfering users ?
826
Yes
No
Issue an Error signal
818
Instruct the User
unit ID # to stop
820
Go to "A"
In fig. 800 (b)
STOP
822

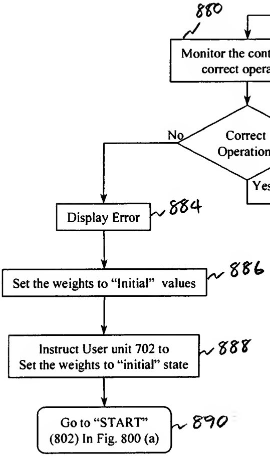
800 (b)


"A"
Select an unused Code-Offset
828
Inform user unit (702) of the Allocated Code-offset
830
"C"
enter the channel-sounding mode
832
Instruct the User unit (702) To enter the channel-sounding mode
834
Instruct user unit 702 to commence Channel-sounding operation.
836
Set the network unit (602) "Initial" Weights
838
Start transmission of cal. Signal (622) with the specified Code Offset
840
Modify the Weights to increase Transmit Power by dG only and transmit With specified Code-offset
848
Perform Channel-response detection
842
844
Channel response Detected?
No
Yes
846
System Gain = Max. allowed?
No
Yes
852
Converge Adaptive algorithm For the transmit weights
854
Set the transmitter Weights
Freeze the most recent Weights
850
856
Weights sufficiently converged?
No
Yes
Go to "B" In Fig 800 (c)

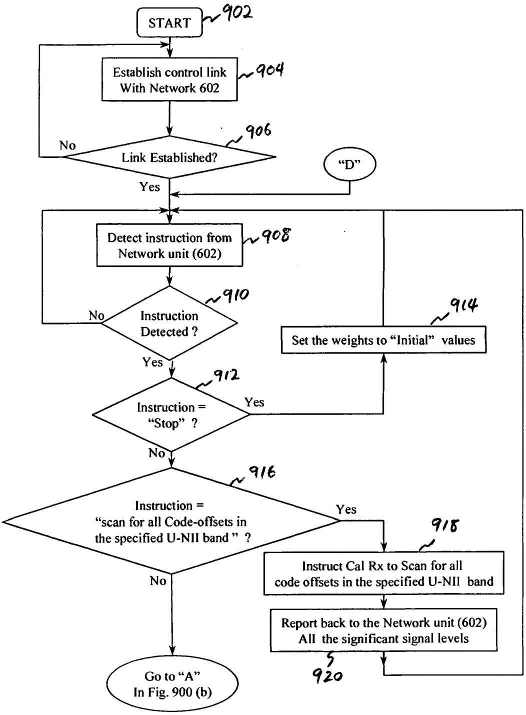
800 (c)


"B"
Wait for User unit (702) Weight Convergence confirmation
858
User Unit (702) Weights Converged?
860
No
Yes
Instruct User unit (702) to exit Channel-sounding mode
862
Exit channel sounding mode
864
Set calibration receiver (620) to receive Network unit (602) "Own Code Offset"
866
Ave. signal Power > Allowed
868
Yes
Go to "C" In Fig. 800 (b)
No
Receive and Detect the "Other Code Offsets"
870
Signal Detected?
872
Yes
No
User unit (702) Reported problems?
874
No
Yes
Go to "START" (802) In Fig. 800 (a)
876

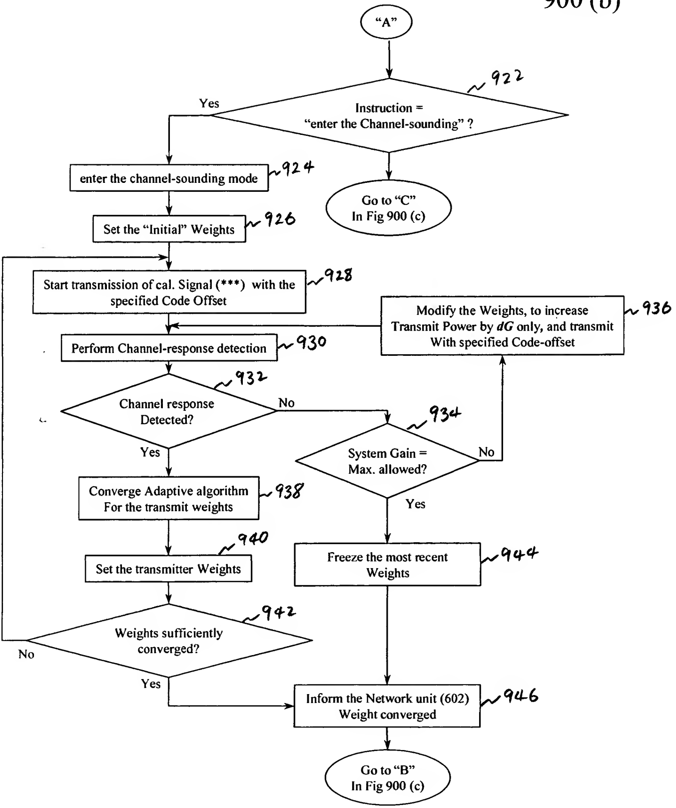
820


880
Monitor the control link correct operation
882
Correct Operation?
No
Yes
884
Display Error
886
Set the weights to "Initial" values
888
Instruct User unit 702 to Set the weights to "initial" state
890
Go to "START" (802) In Fig. 800 (a)

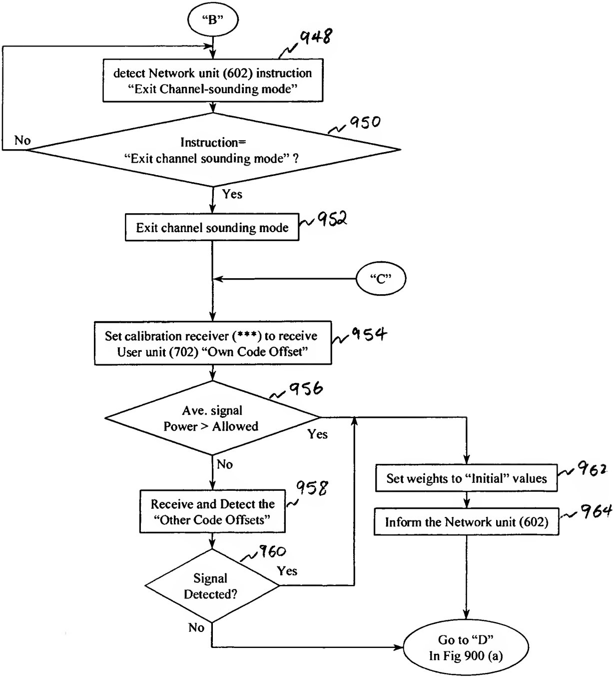
900 (a)


START
902
Establish control link
With Network 602
904
906
No
Link Established?
Yes
"D"
Detect instruction from
Network unit (602)
908
910
No
Instruction
Detected ?
Yes
914
Set the weights to "Initial" values
912
Instruction =
"Stop" ?
Yes
No
916
Instruction =
"scan for all Code-offsets in
the specified U-NII band" ?
Yes
No
918
Instruct Cal Rx to Scan for all
code offsets in the specified U-NII band
Report back to the Network unit (602)
All the significant signal levels
920
Go to "A"
In Fig. 900 (b)

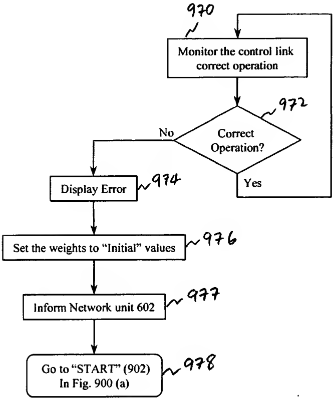
900 (b)

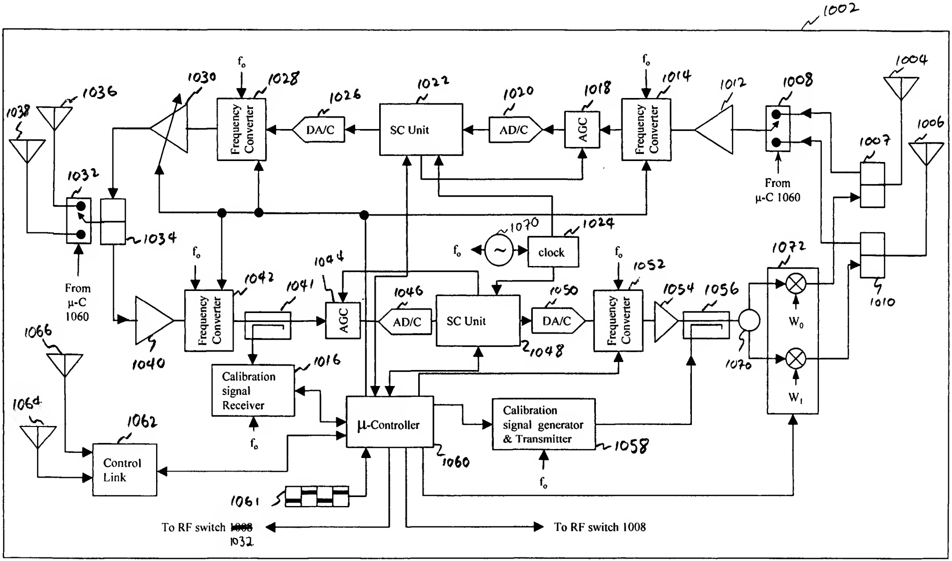

"A"
Instruction =
"enter the Channel-sounding" ?
922
Yes
enter the channel-sounding mode
924
Go to "C"
In Fig 900 (c)
Set the "Initial" Weights
926
Start transmission of cal. Signal (***) with the specified Code Offset
928
Modify the Weights, to increase Transmit Power by dG only, and transmit With specified Code-offset
936
Perform Channel-response detection
930
932
Channel response Detected?
No
934
System Gain = Max. allowed?
No
Yes
Converge Adaptive algorithm For the transmit weights
938
Yes
Set the transmitter Weights
940
Freeze the most recent Weights
944
942
Weights sufficiently converged?
No
Yes
Inform the Network unit (602) Weight converged
946
Go to "B"
In Fig 900 (c)

900 (c)


"B"
948
detect Network unit (602) instruction "Exit Channel-sounding mode"
950
No
Instruction= "Exit channel sounding mode" ?
Yes
Exit channel sounding mode
952
"C"
Set calibration receiver (***) to receive User unit (702) "Own Code Offset"
954
956
Ave. signal Power > Allowed
Yes
No
Set weights to "Initial" values
962
958
Receive and Detect the "Other Code Offsets"
Inform the Network unit (602)
964
960
Yes
Signal Detected?
No
Go to "D" In Fig 900 (a)

910


970
Monitor the control link correct operation
972
Correct Operation?
No
Yes
Display Error
974
Set the weights to "Initial" values
976
Inform Network unit 602
977
Go to "START" (902) In Fig. 900 (a)
978


1002
1004
1006
1007
1008
1010
1012
1014
1016
1018
1020
1022
1024
1026
1028
1030
1032
1034
1036
1038
1040
1041
1042
1044
1046
1048
1050
1052
1054
1056
1058
1060
1061
1062
1064
1066
1070
1072
f₀
Frequency Converter
DA/C
SC Unit
AD/C
AGC
From μ-C 1060
clock
Calibration signal Receiver
μ-Controller
Calibration signal generator & Transmitter
Control Link
W₀
W₁
To RF switch ~~1008~~ 1032
To RF switch 1008

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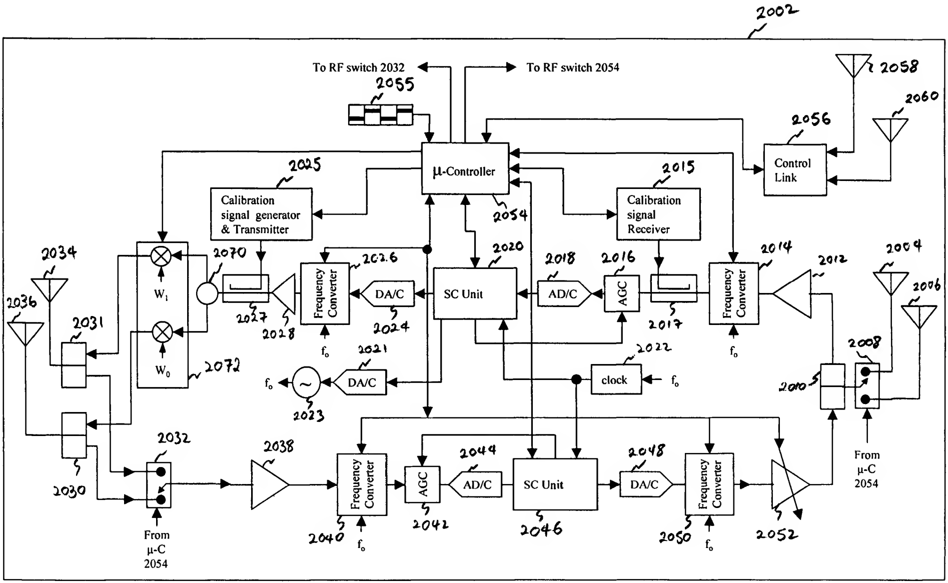
2000



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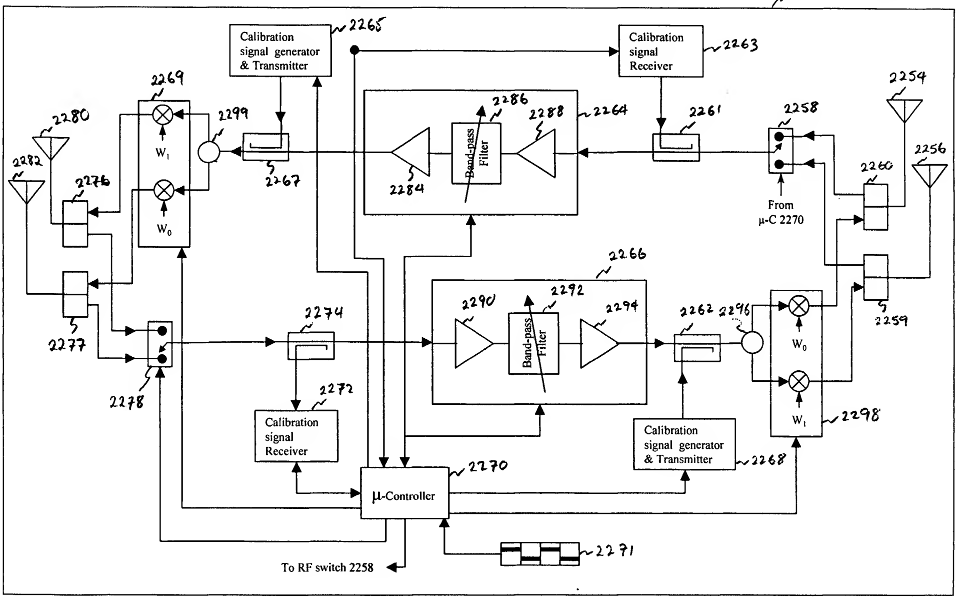
2250


2252
2265
Calibration signal generator & Transmitter
Calibration signal Receiver
2263
2269
W1
W0
2299
2280
2282
2276
2277
2267
2284
Band-pass Filter
2286
2288
2264
2261
2258
From μ-C 2270
2254
2256
2260
2259
2266
2290
2292
2294
2262
2296
W0
W1
2298
2274
2272
Calibration signal Receiver
2278
μ-Controller
2270
Calibration signal generator & Transmitter
2268
2271
To RF switch 2258

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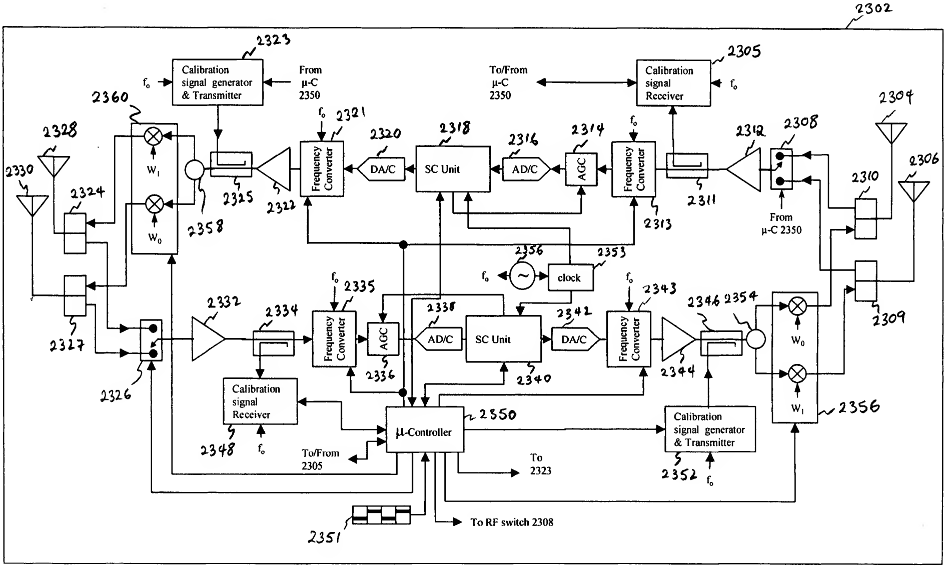
2300



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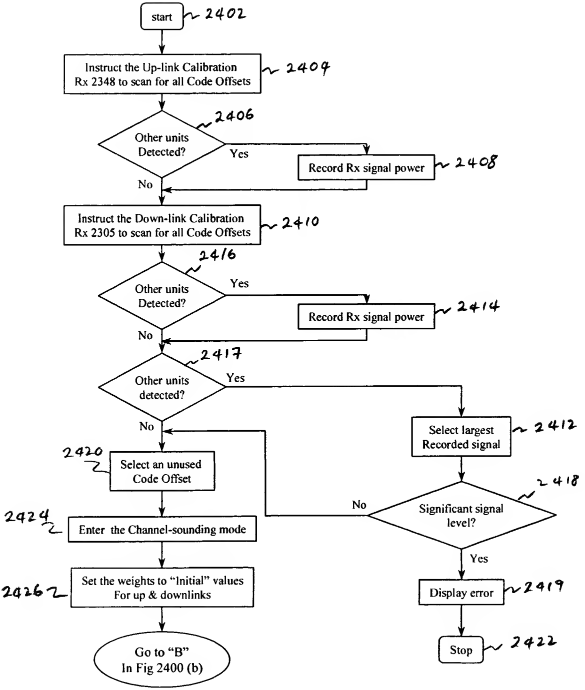
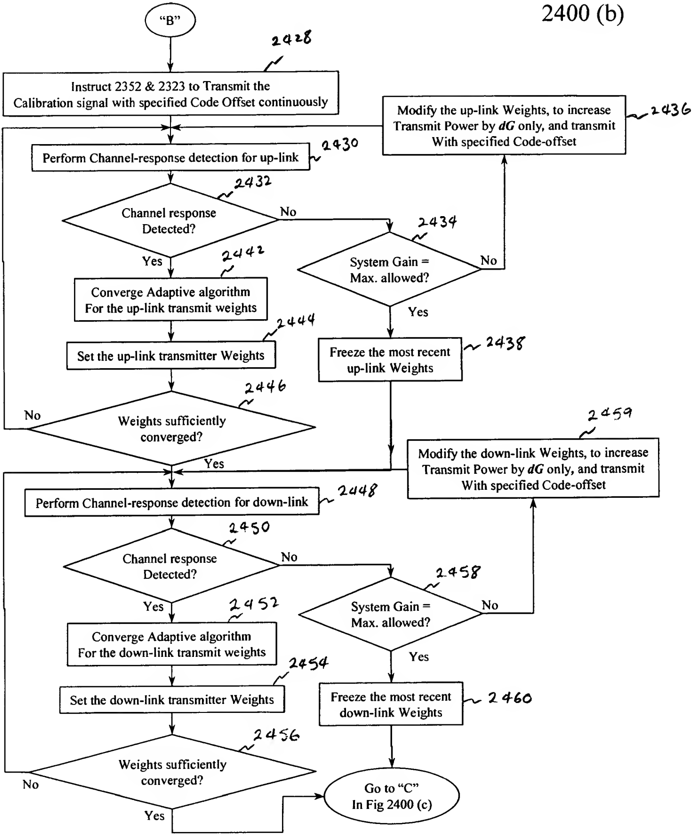
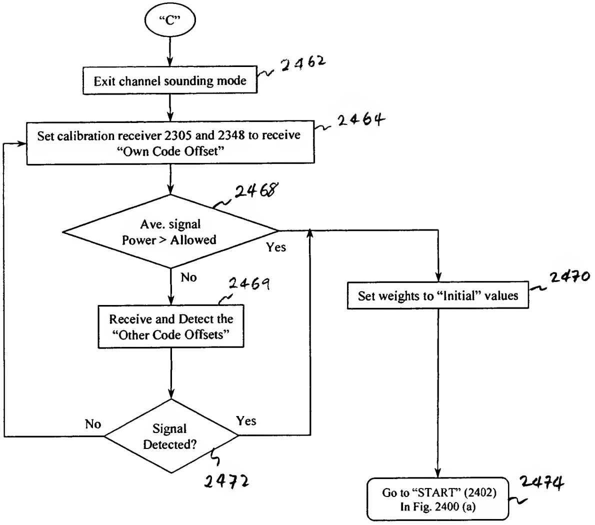
2400 (a)


start
2402
Instruct the Up-link Calibration Rx 2348 to scan for all Code Offsets
2404
2406
Other units Detected?
Yes
Record Rx signal power
2408
No
Instruct the Down-link Calibration Rx 2305 to scan for all Code Offsets
2410
2416
Other units Detected?
Yes
Record Rx signal power
2414
No
2417
Other units detected?
Yes
No
Select largest Recorded signal
2412
2420
Select an unused Code Offset
2418
No
Significant signal level?
2424
Enter the Channel-sounding mode
Yes
Set the weights to "Initial" values For up & downlinks
2426
Display error
2419
Go to "B" In Fig 2400 (b)
Stop
2422

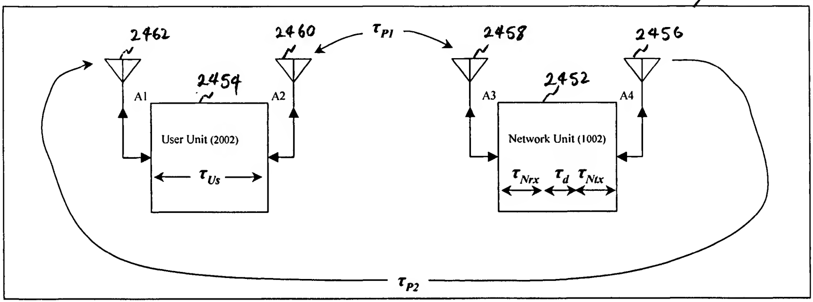
2400 (b)

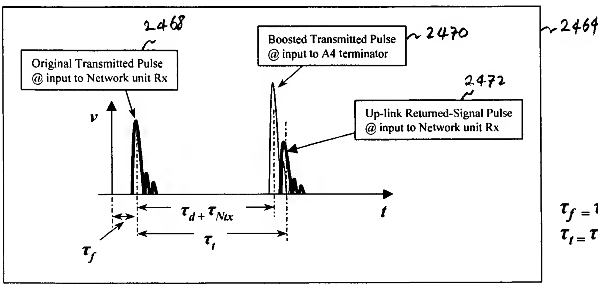

"B"
2428
Instruct 2352 & 2323 to Transmit the Calibration signal with specified Code Offset continuously
Modify the up-link Weights, to increase Transmit Power by *dG* only, and transmit With specified Code-offset
2436
Perform Channel-response detection for up-link
2430
2432
Channel response Detected?
No
2434
System Gain = Max. allowed?
No
Yes
2442
Converge Adaptive algorithm For the up-link transmit weights
Yes
2444
Set the up-link transmitter Weights
Freeze the most recent up-link Weights
2438
2446
No
Weights sufficiently converged?
Yes
2459
Modify the down-link Weights, to increase Transmit Power by *dG* only, and transmit With specified Code-offset
Perform Channel-response detection for down-link
2448
2450
Channel response Detected?
No
2458
System Gain = Max. allowed?
No
Yes
2452
Converge Adaptive algorithm For the down-link transmit weights
Yes
2454
Set the down-link transmitter Weights
Freeze the most recent down-link Weights
2460
2456
Weights sufficiently converged?
No
Yes
Go to "C" In Fig 2400 (c)

2400 (c)


"C"
Exit channel sounding mode
2462
Set calibration receiver 2305 and 2348 to receive "Own Code Offset"
2464
Ave. signal Power > Allowed
2468
Yes
No
Set weights to "Initial" values
2470
2469
Receive and Detect the "Other Code Offsets"
Signal Detected?
No
Yes
2472
Go to "START" (2402) In Fig. 2400 (a)
2474

2450





$$\tau_f = \tau_{Us} + \tau_{P1} \simeq \tau_{P1}$$
$$\tau_t = \tau_{Nrx} + \tau_d + \tau_{Ntx} + \tau_{P2} + \tau_f \simeq \tau_d + \tau_{P2} + \tau_{P1}$$

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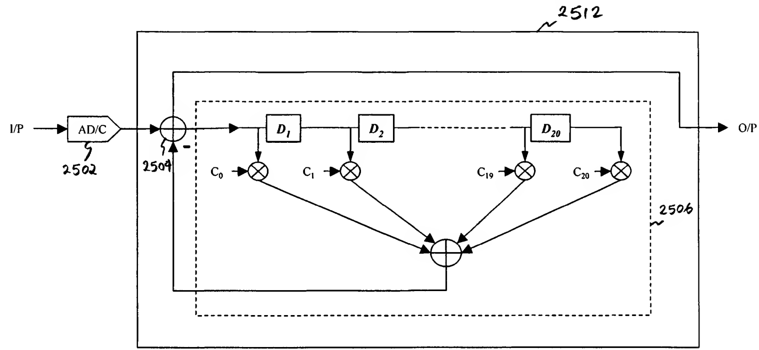
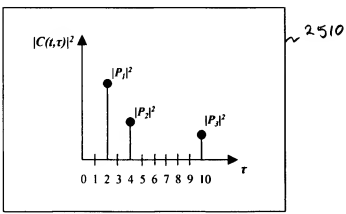
2500





$C_0 = 0$	$C_{11} = 0$
$C_1 = 0$	$C_{12} = P_1$
$C_2 = 0$	$C_{13} = 0$
$C_3 = 0$	$C_{14} = P_2$
$C_4 = 0$	$C_{15} = 0$
$C_5 = 0$	$C_{16} = 0$
$C_6 = 0$	$C_{17} = 0$
$C_7 = 0$	$C_{18} = 0$
$C_8 = 0$	$C_{19} = 0$
$C_9 = 0$	$C_{20} = P_3$
$C_{10} = 0$	

2508

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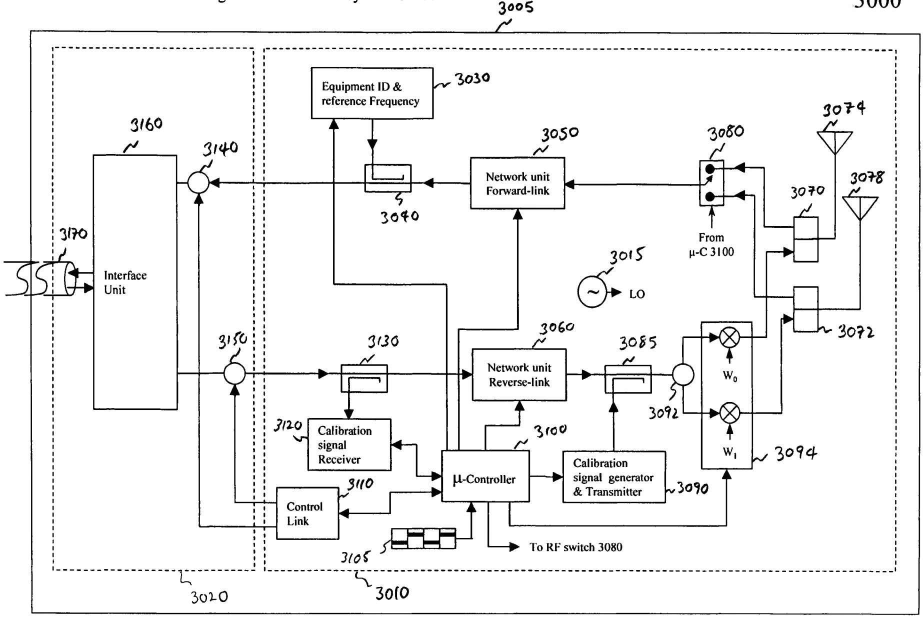
3005
Equipment ID & reference Frequency
3030
3160
3140
3050
Network unit Forward-link
3080
3074
3040
3070
3078
3170
Interface Unit
From μ-C 3100
3015
LO
3060
3072
3150
3130
3085
Network unit Reverse-link
W0
3092
3120
Calibration signal Receiver
3100
W1
3094
μ-Controller
Calibration signal generator & Transmitter
3110
3090
Control Link
3105
To RF switch 3080
3020
3010

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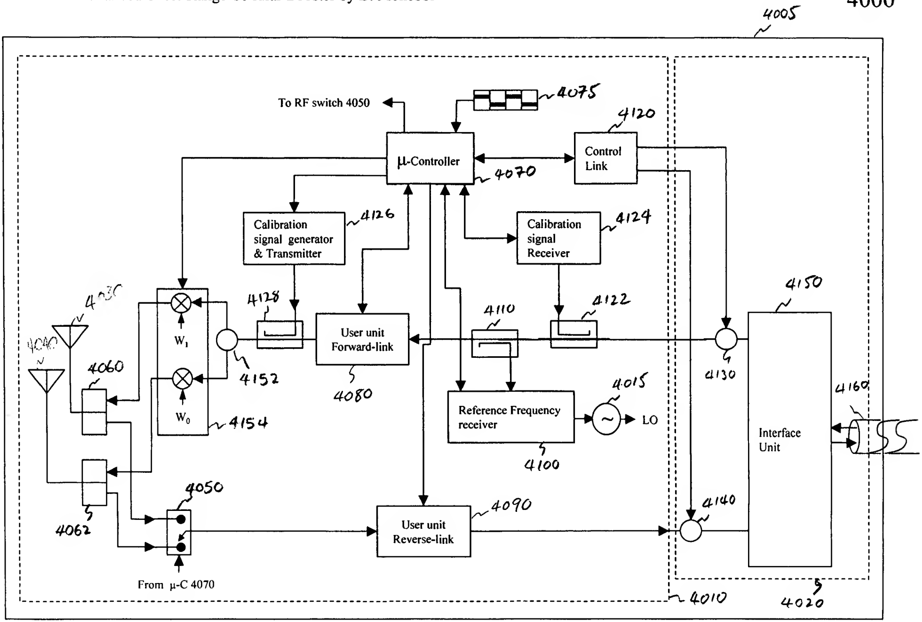
4000



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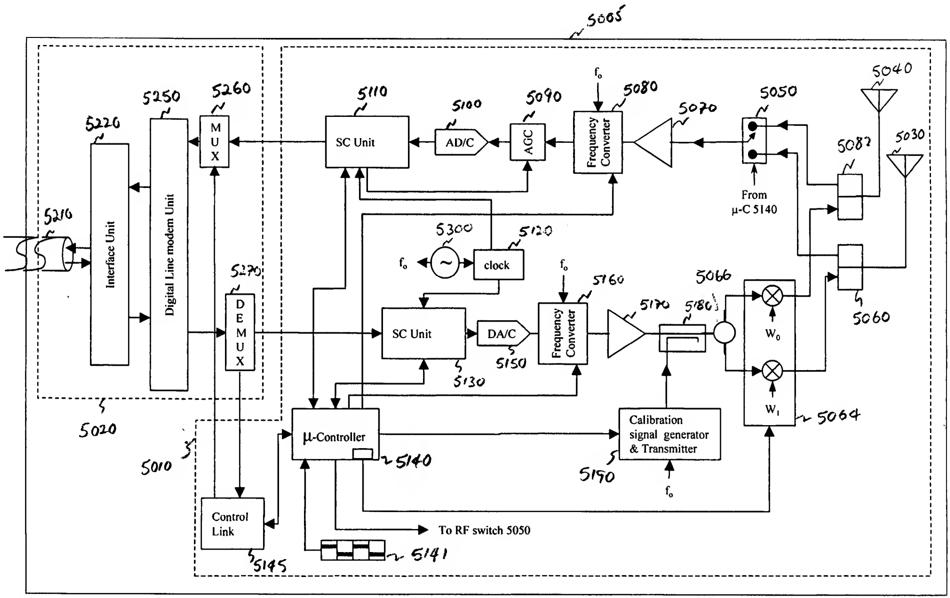
5000



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Advanced Short-Range Cellular Booster by B. Mohebbi

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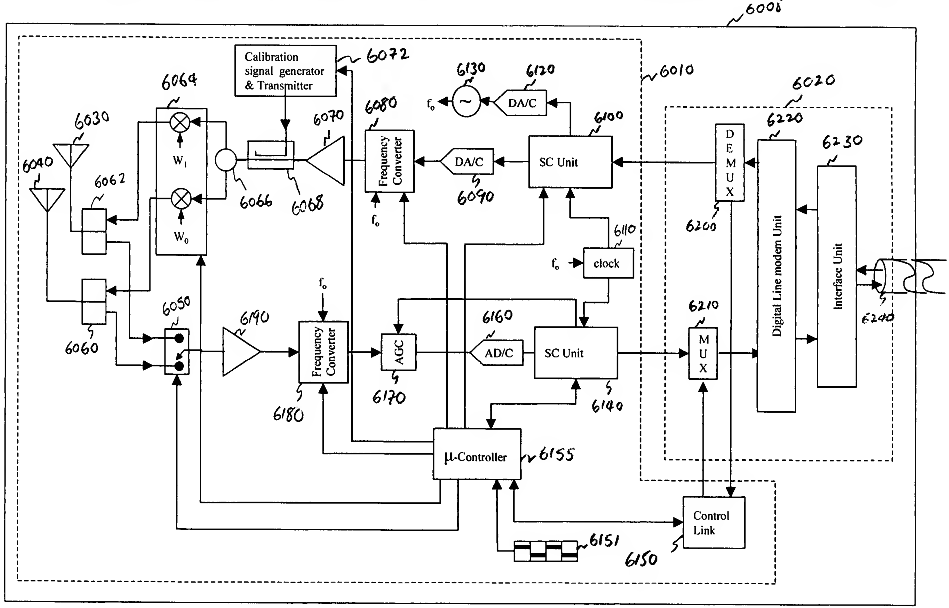
6000



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